US Army Corps
of Engineers
Omaha District

AGGRADATION, DEGRADATION, AND WATER QUALITY CONDITIONS

MISSOURI RIVER MAINSTEM RESERVOIR SYSTEM

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Prepared for

Missouri River Water Control
Master Manual Update

Prepared by

Rivers & Reservoir Engineering Section
Hydrologic Engineering Branch
Engineering Division
Omaha, District

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Evaluate changes in channel geometry for survey ranges along the study reaches of the Missouri River mainstem reservoirs

Analyse the reservoir volume by segment data to determine the depletion of reservoir capacity within each bounded volume segment

Analyse the spatial and temporal trends in the 50 percent coarser bed material gradation by plotting sediment grain size data versus distance along the river for the period of record

Plot cumulative streambank erosion data, identifying any spatial or temporal trends in the shoreline erosion processes

Prepare and evaluate stage trends and tailwater trends of each dam

Provide an overview of water quality conditions in the lakes.

Four states are included in the study area: Montana, North Dakota, South Dakota, and Nebraska. The study reach begins at the head of Fort Peck Lake (River Mile (RM) 2067.8) and extends downstream along the Missouri River to Ponca, Nebraska (1960 RM 753.6), spanning a distance of 1,314 valley miles.

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INTRODUCTION

PURPOSE

The purpose of this study is to compile a record of pertinent data and information relative to aggradation, degradation, and water quality within the system of six Missouri River mainstem reservoirs and to analyze these data to determine trends in geomorphologic changes during the period of record. Specific objectives include:

a. Evaluate changes in channel geometry for survey ranges along the study reaches of the Missouri River mainstem reservoirs. This includes plotting and analyzing the channel width profiles, average bed elevations, thalweg elevations, and cross-section area profiles.

b. Analyze the reservoir volume by segment data to determine the depletion of reservoir capacity within each bounded volume segment.

c. Analyze the spatial and temporal trends in the 50 percent coarser bed material gradation by plotting sediment grain size data versus distance along the river for the period of record.

d. Plot cumulative streambank erosion data, identifying any spatial or temporal trends in the shoreline erosion processes.

e. Prepare and evaluate stage trends and tailwater trends of each dam.

f. Provide an overview of water quality conditions in the lakes.

STUDY AREA

Four states are included in the study area: Montana, North Dakota, South Dakota, and Nebraska. The study reach begins at the head of Fort Peck Lake (River Mile (RM) 2067.8) and extends downstream along the Missouri River to Ponca, Nebraska (1960 RM 753.6), spanning a distance of 1,314 valley miles. A Missouri River Division basin map and pertinent data table are located on Plates 1 and 2, respectively.

DESCRIPTION OF MISSOURI RIVER RESERVOIR SYSTEM

The Missouri River mainstem system of dams is composed of six large earth embankments, which impound a series of lakes that extends for 1,257 miles from Gavins Point Dam near Yankton, South Dakota to the headwaters of Fort Peck Lake north of Lewiston, Montana. These were constructed by the Corps of Engineers on the mainstem of the Missouri River for flood control, navigation, irrigation, power, water supply, water quality control, recreation, and fish and wildlife enhancement. Fort Peck Dam, the oldest of the six, was closed in 1937, and its embankment volume of 77,018 acre-feet makes it the largest hydraulic fill earthen dam in the world. Fort Randall Dam was closed in 1952, followed by Garrison Dam in 1953, Gavins Point Dam in 1955, Oahe Dam in 1958 and Big Bend Dam in 1963. At the top of their Carryover and Multiple Use pools, the lakes behind these six dams provide nearly 988,418 acres of water surface area and extend a total length of 750 miles. Only 325 miles of open river remain between the lakes, although there are 811 miles of open river downstream from the Gavins Point Dam to the mouth of the Missouri River where it enters the Mississippi River at St. Louis, Missouri. The reservoirs contain an aggregate storage space of 73.6 million acre-feet, more than three times the average annual flow of the Missouri River at Souix City, Iowa.

PERTINENT DATA

DATA RESOURCES

The majority of the information utilized in this report was obtained from the Omaha District data base. This includes data collected by the U.S. Army Corps of Engineers (COE) as well as other agencies, including the U.S. Geological Survey (USGS). The Omaha District has been collecting and storing sediment-related data for over 50 years, including cross-sections, suspended sediment loads, and bed material data. The majority of this information consists of station-elevation cross-section data, collected since 1938 by Omaha District personnel or A-E contract at the district's six Missouri River mainstem (and 22 tributary) reservoirs. To date, a total of 664 permanent cross sections (sediment rangelines) have been established in the district (376 permanent sediment rangelines have been established on the tributary projects). The order of establishment initially determined range numbers. However, additional ranges created in this system led to confusion. For example, in the Fort Peck Lake aggradation reach, range 5 occurred geographically between ranges 48 and 49. Since the same problem was noted at other mainstem Missouri River reservoirs, a more coherent system was adopted. The "1941 Adjusted Missouri River Mileage" became the identifier for all river and reservoir ranges from below Gavins Point Dam to above Fort Peck Lake. It identifies the ranges as measured from the mouth of the Missouri River along the channel thalweg on the 1933-34 topographic maps. Tributary ranges are identified by the use of prefix letters. Although range numbers consistent with 1941 river miles are still maintained for the data base, all river distances in this report refer to the 1960 River Mile scale.

Aggradation/degradation resurveys are a major part of the field activities. Until about 1975 these were done by Government labor at regularly scheduled intervals, but since have been handled by A-E contract on all but the smaller tributary lakes. The work entails periodic resurveys of the land surface and riverbed elevations between permanent survey monuments at specific range locations. Complete resurveys are normally scheduled at fifteen-year intervals for Ft. Peck, Garrison, and Oahe, at ten-year intervals for Ft. Randall, Big Bend and Gavins Point, and approximately ten-year intervals for tributary projects. The resurvey schedule is based upon several criteria: (1) Historic data trends -- higher sediment load reservoirs require more frequent surveys; (2) Size of reservoir -- larger reservoirs require less frequent surveys; (3) Project purposes -- reservoirs providing flood protection to high population areas require more frequent surveys; (4) Water rights -- reservoirs containing storage committed to irrigation, water supply, and other water rights require more frequent surveys; and (5) Practical problem considerations -- less frequent surveys may cause problems of lost sediment range monuments, ungaged high sediment inflows from large floods, and undetected changes in upstream watershed land use. Occasionally, depending on special study needs, partial surveys are made at key range locations to document delta growth patterns and backwater channel hydraulic characteristics. Table 3 shows the tentative schedule of hydrographic resurveys for the next fifteen years. Other data collected during the surveys, in addition to range profile data, include: (1) bed surface samples or density probe measurements in the reservoir backwater reaches (the choice of measurement depends on coarseness of the bed material); (2) bed surface samples at each range through the degradation reach; (3) suspended depth-integrated samples and velocity measurements at range locations where bed surface samples were taken; and (4) water surface profile measurements when permitted by steady state discharges.

GEOGRAPHY

The Missouri River begins at the confluence of the Gallatin, Madison, and Jefferson Rivers in southwestern Montana, near the town of Three Forks, and it flows generally east and south about 2,316 miles to join the Mississippi River just upstream from St. Louis. The Missouri River basin has an area of 529,350 square miles, including about 9,700 square miles in Canada. That part within the United States extends over one-sixth of the Nation's area, exclusive of Alaska and Hawaii. It includes all of Nebraska; most of Montana, Wyoming, North Dakota, and South Dakota; about half of Kansas and Missouri; and smaller parts of Iowa, Colorado, and Minnesota.

TOPOGRAPHY

The Rocky Mountains form the basin's western boundary. They have an exceptionally rugged topography, with many peaks surpassing 14,000 feet in elevation. The mountains extend over an area of 56,000 square miles. The area contains many valleys; however, the peaks and mountain spurs dominate the area.

Sloping eastward from the Rocky Mountains, the Great Plains form the heartland of the basin. This broad belt of highlands covers approximately 370,000 square miles (sq. mi.) The eastern boundary lies along the 1,500-foot contour. The western boundary at the foot of the Rocky Mountains averages about 5,500 feet in elevation. West-to-east slopes average about ten feet to the mile. South and west of the Missouri River, the surface mantle and topography have been developed largely by erosion of fluvial plain extending eastward from the mountains. North and east of the Missouri River, and even extending south of the river in some places, the Great Plains have been affected by continental glaciation. Here, the topography was shaped primarily by erosion of the glacial drift and till. Within the Great Plains, there are isolated mountainous areas developed by erosion of dome-like uplifts. Principal among these are the Black Hills of western South Dakota and northeastern Wyoming, extending over an elliptical area 60 miles wide and 125 miles long.

The Central Lowlands border the Great Plains to the east, and often there is no perceptible line of demarcation between them. Roughly, the Central Lowlands extend from a line between Jamestown, North Dakota, and Salina, Kansas, eastward to the drainage divide between the Missouri and Mississippi Rivers. This entire area of 90,000 (sq. mi.) has been developed by erosion of a mantle of glacial drift and till. The northern portion is covered by the coarser drift material, while the finer till is dominant in the southern portion.

In the southeastern part of the basin, in southern Missouri, an area of about 11,000 (sq. mi.) of the basin lies in the Ozark Plateau. The topography here, developed by erosion of the Ozark uplift, is hilly to mountainous. Sedimentary rocks are left exposed. The basic surface material is limestone, and cavernous channels with spring flows abound in the area. Plate 3 shows the physiographic features discussed above.

CLIMATOLOGY

The broad range in latitude, longitude, and elevation of the Missouri River basin and its location near the geographical center of the North American Continent result in a wide variation in climatic conditions. The climate of the basin is produced largely by interactions of three great air masses that have their origins over the Gulf of Mexico, the northern Pacific Ocean, and the northern polar regions. They regularly invade and pass over the basin throughout the year, with the Gulf air tending to dominate the weather in summer and the polar air dominating it in winter. This seasonal

domination by the air masses and the frontal activity caused by their collisions produce the general weather regimens found within the basin. As is typical of a continental-interior plains area, the variations from normal climatic conditions from season to season and from year to year are very great. The outstanding climatic aberration in the basin was the severe plains area drought of the 1930's when excessive summer temperatures and subnormal precipitation continued for more than a decade.

Normal average annual precipitation ranges from as low as 8 to 10 inches just east of the Rocky Mountains to about 40 inches in the southeastern part of the basin and in parts of the Rocky Mountains. The pattern of normal annual precipitation over the basin is shown on Plate 4. Prolonged droughts of several years duration and frequent shorter periods of deficient moisture, interspersed with periods of abundant precipitation, are characteristic of the plains area.

Deep cyclones and accompanying frontal systems, moving from the southern great plains states toward the northeast, can cause widespread precipitation over the basin during all seasons of the year due to the resulting influx of moist maritime tropical air from the Gulf of Mexico. Cyclonic activity over the basin is at a maximum during the late winter and early spring months and decreases to a minimum during the late summer and early fall months. The moisture-carrying ability of an air mass is dependent upon the temperature of the mass and is normally at a maximum at mid-summer and at a minimum in mid-winter.

Precipitation during the late summer and fall months is usually of the short-duration thunderstorm type with small centers of high intensity, although widespread general rains occasionally occur, especially in the lower basin. Winter precipitation usually results from the passage of well-developed low-pressure systems and active fronts. This precipitation occurs in the form of snow in the northern and central portions of the basin; however, in the lower basin states it may occur as either rain or snow or a mixture of both. Winter precipitation is, in general, considerably less that at other seasons of the year due to the decreased moisture-carrying ability of the colder air masses and due to the barrier imposed by the Rocky Mountains to the westerly circulation which generally prevails through this season.

Precipitation during the period from November through March is generally in the form of snow. Normally the basin has fairly frequent light winter snows, interspersed with a few heavy storms. The average annual snowfall over the plains increases from south to north. It ranges from 20 inches in the lower basin, to 30 inches in the eastern Dakotas and to near 50 inches in the high plains areas in the west. High elevation stations in the Black Hills and in the Rockies along the western edge of the basin receive in excess of 100 inches of snowfall. Following the winter season, snow depths up 6 feet, with a water equivalent of 24 inches, are not uncommon at mountain locations. Snow does not usually progressively accumulate over the plains, but is melted by intervening thaws. However, there have been exceptions over the northern plains when snow accumulated on the ground by the end of winter had a water equivalent of 6 inches or more in some years.

Temperatures in the basin are noted for fluctuations and extremes because of the basin's mid-continent location. Winters are relatively long and cold over much of the basin, while summers are fair and hot. Spring is normally cool, humid, and windy, while autumn is normally cool, dry, and fair. Temperature extremes range from winter lows of -60 degrees fahrenheit in Montana to summer highs that may exceed 115 degrees fahrenheit in Nebraska, Kansas, and Missouri. The basin regularly experiences temperatures about 100 degrees fahrenheit in summer and below 0 degrees fahrenheit in winter over most of its area.

RESERVOIR CAPACITY DEPLETION

DESCRIPTION OF RESERVOIR STORAGE ZONES

The total loss of reservoir storage due to sedimentation is an important operating parameter; however, the distribution of these deposits within storage zones in the pool are of particular interest. Four zones are analyzed in this section: Permanent Pool, Carryover and Multiple Use zone, Annual Flood Control and Multiple Use zone, and Exclusive Flood Control zone. The Permanent Pool is from the top of the permanent pool elevation to the bottom of the reservoir. The Carryover and Multiple Use zone is from the top of the carryover multiple use pool elevation to the top of the permanent pool elevation. The Annual Flood Control and Multiple Use zone is from the top of the annual flood control and multiple use pool elevation to the carryover and multiple use pool elevation. The Exclusive Flood Control zone is from the top of the exclusive flood control pool elevation to the top of the annual flood control and multiple use pool elevation. Plate 5 shows the location of each zone within the reservoir. A discussion of the purpose of these four zones is as follows.

Permanent Pool

A bottom zone provides minimum power head and sediment storage capacity. It also serves as a minimum pool for recreation, fish and wildlife, and pump diversion of water from the reservoir. Reservoir drawdown into this zone is not scheduled except in an unusual emergency.

Carryover and Multiple Use Zone

An intermediate zone provides a storage reserve for irrigation, navigation, power production, fish and wildlife, recreation, and other beneficial conservation uses. At the major projects (Fort Peck, Garrison, and Oahe) the storage space in this zone provides carryover storage for maintaining downstream flows through a succession of well below normal runoff years.

Annual Flood Control and Multiple Use Zone

An upper "normal operating zone" is reserved annually for retention of normal flood flows and for annual multiple use regulation of the impounded flood waters. The capacity in this zone, which is immediately below the top zone reserved for exclusive flood control, is normally evacuated to a predetermined level by about March to provide adequate storage capacity for the flood season. This level remains more or less fixed from year to year.

Exclusive Flood Control Zone

A top zone in each reservoir is reserved exclusively for flood control. The storage space therein is utilized only for detention of extreme or unpredictable flood flows, and is evacuated as rapidly as feasible within limitations imposed by considerations of flood control. These considerations include project release limitations, status of storage in the other mainstem projects and the level of system releases being maintained. Table 1 shows the top elevations of each zone in each reservoir (in feet above mean sea level (msl)).

TABLE 1

ZONE ELEVATION (msl)

	FORT PECK	GARRISON	OAHE	BIG BEND	FORT RANDALL	GAVINS POINT
TOP PERMANENT POOL	2160	1775	1540	1420	1320	1204.5
TOP CARRYOVER MULTIPLE USE ZONE	2234	1837.5	1607.5	1420	1350	1204.5
TOP ANNUAL FLOOD CONTROL and MULTIPLE USE ZONE	2246	1850	1617	1422	1365	1208
TOP EXCLUSIVE FLOOD CONTROL RESERVE	2250	1854	1620	1423	1375	1210

GENERAL COMMENTS

Plate 6 shows a comparison of capacity depletion by zone for each of the pool zones for each reservoir. Plates 7 and 8 show a more detailed breakdown of losses by zone. The mainstem system was not entirely operational until about 1967 when all of the reservoirs were finally filled. A large amount of the material depositing in the lower elevation zones occurred during this prolonged reservoir filling period. The Permanent Pool has by far the highest capacity depletion of the three zones. In the Permanent Pool approximately 8 percent of Fort Peck, 3.5 percent of Garrison, 4 percent of Oahe, 5.5 percent of Big Bend, 20.5 percent of Fort Randall, and 16 percent of Gavins Point capacity have been lost.

Wide variations in pool level fluctuations also exist between projects, which have affected the locations of sediment deposits. It is apparent, however, that most deposits exist in a zone that is slightly below the prevailing pool level at the time of the sediment inflow. The six reservoirs formed by the dams vary in length from a minimum of about 25 miles to nearly 250 miles, thus the location of the sediment deposits vary significantly longitudinally throughout the reservoirs. The majority of the sediment begins to settle out 10 to 15 miles downstream from the upstream end of the pools, and is concentrated within a 30-mile reach downstream from this point. Sediment deposits of any significant quantity have not been observed in the vicinity of the dams and/or powerhouses at any of the six dams. Most of the sediment that presently exists in the lower elevation zones of the pools was deposited during the reservoir filling period, and little change has been noted in these volumes since the projects were first filled.

SUMMARY OF GEOMORPHOLOGICAL ANALYSIS

The Missouri River morphologic conditions and trends discussed herein consist of evaluations of pool elevation, channel geometry, longitudinal reservoir capacity depletion, spatial and temporal trends in the bed material grain size distribution, stage and tailwater trends, and river bank erosion for the aggradation and degradation reach of each mainstem project. A general discussion of 1) aggradation and degradation processes and 2) the general computation procedure for each parameter analyzed follows.

AGGRADATION

Aggradation occurs when the flow of a stream in the open channel reach enters the backwater reach of a reservoir, the flow velocity decreases, and transported sediment particles begin to fall out. The coarsest sediments deposit first, continuing downstream in a progressive manner, until all of the sand sizes, followed by the silt, and finally the clay size particles have deposited, forming the topset, foreset, and bottomset reaches of the delta. Plate 9 is an illustration of a simple delta profile. Deposition occurring in the channel and along the channel banks results in a narrowing of the channel and resultant increased velocities. The increased velocities allow the aggraded channel to transport its sediment load downstream and further into the reservoir, thereby advancing the topset-foreset breakpoint horizontally into the pool. The bottomset deposits reach is composed of the very fine material carried into and uniformly deposited on the reservoir bottom.

The impact of aggradation on the Missouri River mainstem reservoirs is much greater than the overall impact represented by the relatively small volume losses discussed in the previous chapter. The location of these deposits can negatively impact recreation and water quality and can cause localized flooding problems. Increased river stages associated with aggradation in the backwater reaches of reservoirs can impact non-project lands and levee capacities, increase flooding of urban areas, and/or place restrictions on power generation to reduce associated downstream flooding impacts.

DEGRADATION

Degradation in this report refers to the general erosion of the channel bed and banks over a substantial distance downstream of a dam. It occurs as the sediment-free water released from the dam picks up material from the river bed and banks to obtain a full sediment load compatible with the material available and the river's transport capacity and the river's inability to replace the materials in-kind once they have been removed.

Degradation can cause the lowering of groundwater levels, which in turn can adversely impact wetland areas and drastically reduce the yield of such bottomland crops as corn and alfalfa. The base level lowering of the degrading channel also increases the potential energy gradient at the downstream end of tributaries, resulting in degradation migrating upstream on the tributaries. This tributary degradation often produces geotechnical failure of banks.

AGGRADATION REACH ANALYSIS PARAMETERS

Parameters analyzed for the aggradation reach of each project were thalweg, average bed, capacity depletion and bed material grain size (D_{50}). A discussion of the general calculation procedure for each of these follows.

End of Month Pool Elevation Records

Pool elevation data are taken at each of the mainstem reservoirs on an hourly basis. These data are recorded using a sensor called a Stevens Recorder. The sensor is located on the intake structure of each reservoir except for Big Bend and Gavins Point where the sensor is located in a well on the dam. Data are sent to the Regional Hydropower Action Center (REHAC) at the Gavins Point project and then stored in a data base located at the Missouri River Division (MRD) office.

Thalweg Profile

The thalweg elevation is the lowest observed elevation in the range cross section for any given survey.

Average Bed Profile

The data for the average bed profiles was obtained from hydraulic elements tables. These tables were produced by a computer program that reads cross-section data and computes cross-section width, area, average depth, and average bed elevation by elevation increments. In processing the data, the cross-section width and area values are computed using successive pairs of X-Y input points. Two successive X points are used to define an incremental width for which area is computed. This results in a vertical area slice with a width equal to the difference of the successive X points, and running from the bed elevations at that point to the specified maximum elevation. This process continues across the sedimentation rangeline and a summation is made of the cross-section width at each elevation increment and the total cross-section area from bed to each elevation increment. Average depth for each elevation increment is computed by dividing area by width for that elevation. Average bed is the elevation minus the average depth for each elevation increment.

For the aggradation reach of each project, the average bed was taken as the depth below the specific Top of Exclusive Flood Control. Where the thalweg was within 10 feet of the maximum normal operating pool elevation a sloping water surface elevation reference plane was used. This sloping plane was drawn parallel and 10 feet higher than the average slope of the thalweg profile. Average bed elevations were then calculated below this reference plane at each relevant cross-section. This adjustment was made to Fort Peck Lake, Lake Oahe, and Lewis and Clark projects.

Longitudinal Capacity Depletion Profile

Capacity depletion profiles represent the volume of water in acre-feet of each segment in each reservoir. Reservoir segments are smaller divisions, delimited by range cross-section locations, for routine area-capacity analysis. Volumes are computed using a constant factor method (i.e., the ratio of the original incremental capacity and the sum of the end areas for the bounding ranges). By multiplying this constant factor by the sum of the resurveyed end areas of the bounding ranges, a new volume is computed after each resurvey. Two years were plotted; the closest year to dam closure and the last survey date.

D_{50} Bed Material Profile

Most typically, between four and eight bed surface samples were taken across the section in any survey. Each of these samples was graded by sieve analysis, and, from the individual sample grading data, a composite sediment size was determined for a specific percent passing value. From these, grain size data tabulations of the D_{50}, (50 percent coarser) were made and plotted for each reservoir. In general, samples were obtained between May and September of any given year. It should be noted that these bed samples do not

necessarily represent the bed sediment loads for the actual river, but rather are more likely indicative of the most recently deposited sediments at the sampling location.

DEGRADATION REACH ANALYSIS PARAMETERS

Parameters analyzed for the degradation reach below each dam were adjusted water surface profiles, stage trends, tailwater trends, thalweg, average bed, channel width, cross-section area, bed material grain size, and cumulative erosion.

Adjusted Water Surface Profile

Selected measured water surface profiles were adjusted or shifted to common discharges most closely representing the overall average flow below each dam for the period covered by the water surface profile. The adjustment, or shift value, applied to each water surface profile was the difference between the actual water surface profile elevation and the gaging station rating curve elevation at the selected discharge. The difference was applied to the actual water surface profile elevations on a mileage distance pro-rata basis.

Stage Trends

Gaging station trends analysis consisted of plotting the values of stage for three to four common discharges against a time scale. The stage values for the common discharges were taken from appropriate rating curves.

Tail Water Trends

Hourly powerhouse release tables in conjunction with stage elevation scrolls were used to determine rating curves. From these rating curves, tailwater elevations were determined for discharges of 10,000 cubic feet per second (cfs), 20,000 cfs, and 30,000 cfs and plotted on a time scale.

Thalweg Profile - See Aggradation - Thalweg Profile discussion.

Average Bed Profile

The average bed elevations for the degradation reaches were determined from hydraulic elements analysis in the same manner as those for the aggradation reaches, with the exception of the determination of the reference plane elevations. For these reaches, the reference plane elevation used for each profile was the adjusted water surface elevation corresponding to the survey (profile) year. While this procedure results in a changing reference plane for each plotted profile, it is believed to offer the best representation of channel conditions/trends for average flow conditions.

Active Channel Width Profile

Channel width profiles for each year were determined from hydraulic elements tables using the corresponding adjusted water surface profile as the reference plane elevation.

Channel Cross-section Area Profile

Channel cross-section area values represent the cross-sectional area, from hydraulic elements tables, below the corresponding adjusted water surface profile elevation.

D_{50} Bed Material Profile - See Aggradation - D_{50} Bed Material Profile discussion.

Cumulative Erosion

The cumulative loss of valley lands due to streambank erosion below each dam was determined through comparison of aerial photography.

FORT PECK PROJECT SEDIMENTATION CONDITIONS

DESCRIPTION OF PROJECT

Fort Peck Dam is located on the Missouri River at RM 1772 in northeastern Montana; 17 miles southeast of Glasgow, Montana, and 9 miles south of Nashua. A range location map for the reservoir is shown on Plate 10. Construction of the project was initiated in 1933, closure was made in 1937, and the project was placed in operation for purposes of navigation and flood control in 1938. In 1943 the first unit of the power installation went on the line and the third unit became operational in 1951, completing construction of the initial power plant. Construction of a second power plant began in the late 1950's and the two units of this plant became operational in 1961. The Permanent Pool of the reservoir was initially filled (elevation 2160) in April 1942 and the Carryover and Multiple Use zone (elevation 2234) first filled in 1947. Drought conditions during the late 1950's, combined with withdrawals to provide water for the initial fill of other mainstem projects, resulted in a drawdown of the reservoir level to elevation 2167.4 in early 1956, followed by a generally slow increase in elevation. It was not until July 1964 that the Carryover and Multiple Use zone was refilled. It has remained generally filled from that time through 1976. Exclusive Flood Control storage space was first utilized in 1969 and again in 1970. In 1975, all space allocated for specific functions was filled and a maximum reservoir level 1.6 feet above the base of the surcharge pool occurred.

Prior to 1956, Fort Peck was the only mainstem project with a significant amount of accumulated storage. As a consequence, releases in the 28,000 cfs range were frequently required for navigation purposes, with a maximum mean daily rate of 28,600 cfs in 1948. From late 1956 through early 1975, releases were never significantly in excess of the power plant capacity of the project, amounting to about 15,000 cfs after the second power plant was on line. In 1975, extremely large flood inflows to the project resulted in both maximum experienced reservoir levels and a maximum-of-record mean-daily release of 35,400 cfs Minimum mean daily releases since 1954 have usually been no less than 3,000 cfs; however, mean daily releases as low as 1,000 cfs have occasionally been made.

AGGRADATION REACH

End-of-Month Pool Elevation Records

End-of-month pool elevations for Fort Peck Lake have been recorded by the Corps of Engineers since the autumn of 1937. Until power generation began in 1943, the dam was operated primarily to provide control of downstream navigation flows. Flood control became an important consideration after the lake was filled to the normal operation level in 1945. Plots of the end-of-month pool elevations are presented in Plate 12. The peak end-of-month pool elevation during the period of record was 2251.1 feet msl in August 1975. The minimum was 2167.5 feet msl in February 1956. The average pool elevation in the period 1965 through 1988 was 2440.0 feet msl Between 1989 and 1990, the pool elevation has stayed below the top of the Carryover and Multiple Use zone elevation (2234.0 feet msl).

Thalweg Profile

Plate 13 shows thalweg profile plots for all survey years. The thalweg elevation is the lowest observed elevation in the range cross section for any given survey. Analysis of the thalweg plots show that aggradation in the lake begins near RM 1900 and increases in depth to 20 to 30 feet to near RM 1870. Aggradation depths decrease downstream beyond this point to near RM 1866, downstream of which deposition remains fairly constant in depth. The maximum change in thalweg is nearly 30 feet near RM 1870.

Average Bed Profile

Plate 14 shows average bed profiles for all survey years. The average bed profiles were developed using the maximum operating pool elevation of 2250 feet msl as the reference plane elevation. At the upstream end of the mainstem, where thalweg elevations were at or above 2250 feet msl, a sloping reference plane was used (see Summary of Geomorphological Analysis section for calculation details). Aggradation effects are seen to impact the average bed profile plots over the same ranges and in about the same proportions as for the thalweg plots.

Longitudinal Capacity Depletion (Volume by Segment)

Plate 15 shows the original (1938) and 1986 water volume by segment plots for the mainstem of the reservoir. Most of the loss in volume occurs in the reach upstream of the lake in the vicinity of the confluence of the Musselshell River Arm (RM 1867). Volume losses along the reach between RM 1866 and RM 1937 reaches nearly 50 percent. The gross storage loss for all of Fort Peck Lake between 1938 and 1986 is 869,000 ac-ft (18,100 ac-ft/year), as shown on Plate 7.

D_{50} Bed Material Profile

Evaluation of the D_{50} bed material profiles of Plate 16 shows a relatively erratic series of curves; however, some common trends are observed. In general, a very gradual rise in grain size is noted between RM 1873 (near the confluence of the Musselshell River) and RM 1889 (near the C. K. Creek confluence). A sharper rise in grain size is noted between RM 1889 and RMs 1908 and 1910, where Rock Creek and Sand Creek, respectively, join the mainstem. Almost no change in grain size is noted between RM 1912 and RM 1922, except in the year 1961. The peak noted by the 1961 data may represent a flaw in the data, or unusual runoff for the area during that year. Grain size increases somewhat sharply below the confluence of the mainstem with Sourdough and Armells Creek at about RM 1922 and Two Calf Creek at about RM 1926.

DEGRADATION REACH

The Fort Peck degradation reach extends from Fort Peck Dam (RM 1771.5), downstream nearly 173 miles to RM 1598.77. Two major tributaries affect the degradation reach; they are the Milk River (RM 1961.5) and the Big Muddy Creek (RM 1630.6). A range location map is shown on Plate 11.

Adjusted Water Surface Profile

Water surface profiles, adjusted to a common discharge of 15,000 cfs, are plotted on Plates 17 through 19. Decreasing stage elevations of variable magnitude occur from immediately below the dam to the confluence of the Milk River at RM 1761.6 between years 1950 and 1984. Below the Milk River confluence stage elevations decrease, during this same time period, steadily reducing in magnitude in the downstream direction until the East Frazer Pump Plant is reached at RM 1734.75. Between RM 1734.75 and about RM 1728, stage

elevations decrease at a constant rate, with little variation over time. Downstream from RM 1728, stage elevations decrease almost linearly; the largest decreases, 3 to 4 feet, are noted between RM 1715 and RM 1650. Fluctuations in stage elevation are noted below the confluence of the Big Muddy Creek.

Stage Trends

Seven gaging stations are located along the Fort Peck degradation reach. Stage elevations for flows of 10,000 cfs, 20,000 cfs, and 30,000 cfs are plotted as a function of time on Plates 20 through 26. Degradation effects (lowering stage elevations) in the reach immediately below the dam are seen to occur between years 1950 and 1966. All other gage locations demonstrate a strong trend of lowering stage elevation from 1950 through 1960. In later years, stage stabilization occurred at both the upstream and downstream end of the reach. In the long center section of the river reach, a variable trend of lower stage elevations occurred.

Tailwater Rating Curve Trends

Tailwater rating curves have not been revised since 1966 because periodic evaluations have revealed no significant changes in the rating values. Therefore, a tailwater trends plot has not been provided.

Thalweg Profile

Plates 27 through 29 show thalweg plots for three survey years (1956, 1966, and 1978). Thalweg elevation changes are quite variable with no discernible trends over the entire reach.

Average Bed Profile

Plates 30 through 33 show average bed profiles for three survey years (1956, 1966, and 1978). Analysis of the average bed profile plots shows the following changes.

From approximately two miles below the dam to just downstream of the confluence of the Milk River, bed degradation was relatively steady between 1956 and 1978 for an average decrease in bed elevation of two feet. In general, degradation of one to three feet has occurred downstream of the Milk River to near RM 1660, with the exception of localized aggradation. These localized areas of observed aggradation are likely due to the highly braided characteristic of the stream. Below RM 1660, nearly no degradation occurred between survey years 1966 and 1978.

Active Channel Width Profile

Results of the trend analysis for channel top width (Plate 34), show an erratic series of curves for the reach, consistent with the nature of this parameter. Since the original survey years, little variation in top width values over time is observed, with exceptions noted at RM 1746, 1742, 1735, 1708, 1662, and 1612. The general change in top width reflects streambank erosion.

Channel Cross-Section Area Profile

Analysis of the cross-section area plots (Plate 35), in conjunction with the thalweg, average bed, and channel top width plots, show the following changes. Cross-sectional area increases immediately downstream of the dam to about RM 1712. This change may be attributed to a decrease in thalweg and average bed elevations and a fairly constant channel top width. Cross-section areas increase below RM 1712 until reaching about RM 1666 for survey years

1966 to 1978. Lower thalweg and average bed profile elevation values, as well as slightly larger channel top widths, appear to contribute equally to this change. Below RM 1666, degradation is not as consistent or uniform as for the upstream regions. Cross-section area changes (increases and decreases) reflect changes in thalweg, average bed, and channel top width.

D_{50} Bed Material Profile

Grain size distribution plots (Plate 36) demonstrate the general finding of predominately coarse materials immediately below Fort Peck Dam rapidly followed by a reversal to fine sediments for the remainder of the reach. Three distinctly different areas in the plots are apparent. First, in the extreme upstream reach from Fort Peck Dam downstream to RM 1763, bed materials larger than 1 to 40 millimeters (mm) predominate. Second, materials larger than 0.2 to 1.2 mm predominate between RM 1763 and RM 1750. Third, sediments of 0.2 to 0.3 mm in size are the dominant bed material for the remainder of the downstream reach.

Cumulative Erosion

Cumulative erosion data is incomplete for the Fort Peck degradation reach. No cumulative erosion plots were generated.

GARRISON PROJECT SEDIMENTATION CONDITIONS

DESCRIPTION OF PROJECT

Garrison Dam is located in central North Dakota on the Missouri River at RM 1390, about 75 RM's northwest of Bismarck and 11 miles south of Garrison. A sediment range location map for the reservoir is shown on Plate 37. Construction of the project was initiated in 1946, closure was made in April 1953, and the navigation and flood control functions of the project were placed in operation in 1955. The first power unit of the project went on the line in January 1956, followed by the second and third units in March and August of the same year. Power units 4 and 5 were placed in operation in October 1960. The Garrison Reservoir (Lake Sakakawea) first reached its minimum operating level in late 1955. Due to the drought conditions, it was not until 10 years later, 1965, that the Carryover and Multiple Use zone was first filled. It remained generally filled from that time through 1976. Exclusive Flood Control storage space was used in 1969 and 1975. During 1975, all flood control space was filled and the maximum reservoir level was 0.8 feet above the base of the surcharge pool.

Since 1956, outflows from Garrison Dam have generally been through the power facilities, having a maximum capacity of about 38,000 cfs. An exception was in 1975 when outflows of 65,000 cfs were required for over one month as a result of record-high upstream runoff. The minimum mean daily release since 1956 has been 5,800 cfs.

AGGRADATION REACH

End-of-Month Pool Elevation Records

End-of-month pool elevations for Lake Sakakawea have been recorded by the Corps of Engineers since 1954. The pool elevation gaging station (designated as Gage 06338000 by the USGS) is located on Garrison Dam at RM 1389.9. The plot of the end-of-month pool elevations is presented on Plate 39. The peak end-of-month pool elevation during the period of record was 1,854.7 feet msl in June 1975. This is the only time since the dam has filled that the pool elevation has entered the range designated exclusively for flood control. The minimum elevation since filling is 1815 feet msl in April 1991. The average pool elevation in the period 1954 through July 1991 was approximately 1842.0 feet msl The facility began operation as a flood control project in the spring of 1967.

Thalweg Profile

The thalweg elevation profile plot is presented on Plate 40. The effects of aggradation can be clearly seen for the reach between RM 1548 and RM 1510. Changes in thalweg elevation range from 20 to 25 feet in this reach, with the greatest change occurring near RM 1530. Upstream of RM 1548 the data is highly variable (fluctuating) making it difficult to distinguish temporal trends, although a general aggrading trend has occurred since the original survey conditions.

Average Bed Profile

Plate 41 shows average bed profiles for all survey years. Average bed profiles were developed using the Top of Exclusive Flood Control pool of 1854 feet msl as the reference plane elevation. Changes in average bed are similar to those observed for the thalweg, with the greatest changes occurring between RM 1510 and RM 1548. Little aggradation is apparent downstream of RM 1490.

Longitudinal Capacity Depletion (Volume by Segment)

Plates 42 through 44 show water volume by reservoir segment below elevation 1860 feet msl for the Missouri River portion of Lake Sakakawea for the years 1956 and 1988. From Plate 43 it is seen that the greatest relative change in volume depletion occurs from RM 1524 to RM 1553. This reach corresponds to the greatest changes observed on the bed profile plots. Reservoir water and sediment depletion volumes drop off quickly upstream of RM 1553, with little overall depletion below elevation 1860 feet msl in the segments upstream of RM 1570. The gross storage loss for all of Lake Sakakawea since closure of the dam in 1953 is 907,000 ac-ft (25,900 ac-ft/year), as shown on Plate 7.

D_{50} Bed Material Profile

The D_{50} bed material profile plot of Plate 45 shows a relatively erratic series of curves, however, some common trends can be observed. In general, there is a gradual rise (increasing grain size) for the curves between RM 1533 and RM 1558. This corresponds to the river reach which lies within the upper portion of Lake Sakakawea. The increase in grain size in the upstream direction is consistent with a delta formation process as the Missouri River discharges into the lake, and larger size particles deposit first as stream velocities decrease.

For the reach between RM 1558 and RM 1570, the grain size appears to be relatively constant between the boundaries of the erratic fluctuations. This means that the best-fit curve is approximately horizontal. It can be noted that the 1955 and 1987 curves are not significantly divergent whereas values for intermediate years can show significant departures. It is possible that the fluctuations are a function of preceding stream discharge values.

The final reach within the study area lies between RM 1570 and RM 1590. This reach includes the Yellowstone River confluence vicinity and the Missouri River upstream of the Yellowstone River. This reach again shows an erratic nature, but a slight downward slope trend in the curves (decreasing grain size in the upstream direction) is apparent.

DEGRADATION REACH

The Garrison degradation reach extends from Garrison Dam (RM 1389.9), downstream 54 miles to RM 1335.91. The only major tributary in this reach is the Knife River at RM 1375.72. A range location map is shown on Plate 38.

Adjusted Water Surface Profile

Adjusted water surface profiles are plotted on Plate 46. Profiles were adjusted to a common discharge of 20,000 cfs (the discharge value which most closely represents the overall average flow for the period covered by the water surface profiles). The greatest differences in stage elevation over time (about 4 to 7 feet) occur immediately below the dam and extend about 25 miles downstream to RM 1360. Below RM 1360, stage elevations remain nearly constant between years 1975 and 1985, although they represent a two to four foot decrease from 1958 and 1964.

Stage Trends

Plates 47 through 51 shows the stage-trend plots for gages (Stanton, Fort Clark, Hensler, Washburn, and Price) located in the degradation reach. Elevations were obtained for discharges of 10,000, 20,000, 30,000 cfs. The Missouri River below Garrison Dam experienced a steady lowering trend in stage elevations over the three discharges analyzed from 1955 or 1960 to 1986. At discharges of 30,000 cfs and 20,000 cfs, the average decrease in stage between years 1960 and 1980 is about 4 feet. At a discharge of 10,000 cfs the average decrease in elevation between years 1960 and 1980 was about 2.5 feet. Stages for all discharges began to stabilize or level off for all gages in the mid 1980's.

Tailwater Rating Curve Trends

Plate 52 shows the tailwater trends for 10,000, 20,000, 30,000, and 40,000 cfs. Prior to power operation, tailwater trends fell sharply. Shortly after power generation began in 1956, tailwater elevation continued to decrease, but at a slower rate. Around 1983 the tailwater elevations appear to level off for the higher discharges of 30,000 and 40,000 cfs, and are starting to taper off for the 20,000 and 10,000 cfs discharges.

Thalweg Profile

Plate 53 shows the thalweg profile for the degradation reach. The thalweg profile for this reach is very erratic and it is difficult to draw any trend conclusions, other than over eight feet of degradation has occurred in the eight to ten miles immedialtely below th dam since the 1940's

Average Bed Profile

Plate 54 shows the average bed profile for the years of 1958, 1964, 1975, and 1985. Directly below the dam, the rate of degradation has remained constant between 1958 and 1985, with a maximum observed change of about 8 feet near RM 1384. Downstream of RM 1380, progressive degradation was observed from 1958 to 1975; however, the 1985 average bed profile is at or above the 1975 profile. The degree of degradation observed between 1964 and 1975 is likely reflective of the record outflows observed in 1975.

Active Channel Width Profile

Plate 55 represents a plot of the active channel width versus 1960 RM. A series of erratic curves are shown, although since closure the channel has generally become narrower in the first 20 miles below the dam. Near the confluence of the Knife River at RM 1375, data for the 1958 and 1964 data indicate a channel width in excess of 3,000 feet whereas this same location shows the width to be considerably narrower in 1985. This may indicate the presence of Knife River deposits and the inability of the regulated Missouri River flows to remove them.

Channel Cross-Section Area Profile

The thalweg profile, cross-section width profile and average bed profile together give more understanding to the cross-section area profile shown on Plate 56. Immediately downstream of the dam to RM 1375 the cross-sectional area decreased from 1975 to 1985. This decrease followed an initial increase in cross-sectional area from 1958 and 1964 to 1975 (possibly reflecting record out-flows in 1975). At RM 1372, a sharp decrease in cross-sectional area is present, apparently due to a decrease in channel width. From RM 1364 to RM 1340 the cross-section area becomes more uniform with no definite temporal trends.

D_{50} Bed Material Profile

Plate 57 shows the D_{50} grain size distribution for the degradation reach. It includes data from 1946, 1958, 1964, and 1985. This plot shows an increase in grain size with time. This trend would be indicative of the removal of finer sized sediments as the river tries to regain its full sediment load.

Cumulative Erosion

Plate 58 shows the cumulative erosion in the degradation reach for years 1938 through 1990. Just before the dam closure in 1953, the cumulative erosion was increasing drastically. Once Garrison Dam was in operation, erosion continued, but at a much lower rate. The present trend shows ongoing erosion, but at a much decreased rate.

OAHE PROJECT SEDIMENTATION CONDITIONS

DESCRIPTION OF PROJECT

Oahe Dam is located at RM 1072 of the Missouri River, 6 miles northwest of Pierre, South Dakota. A range location map for Lake Oahe is shown on Plate 59. Construction was initiated on the project in September 1948. Diversion and closure were completed in 1958, and deliberate accumulation of storage was begun in late 1961, just before the first power unit came on line in April 1962. The last of the seven power units became operational in July 1966. The Permanent Pool space in Lake Oahe was first filled in 1962, and the Carryover and Multiple Use space was filled in 1967. Carryover space remained generally filled from that time through 1976, except for seasonal drawdowns in the interest of increased winter power generation.

Due to the control provided by the immediately downstream Big Bend Project, Oahe Dam releases have been extremely variable since the project became fully operational. Minimum mean daily outflows of 1,000 cfs or less are not uncommon, while releases near the power plant capacity of about 55,000 cfs are also frequently made. Since the power plant became operational, practically all releases have been made through the power turbines, with release fluctuations dependent upon the power load being experienced.

AGGRADATION REACH

End-of-Month Pool Elevation Records

Plate 61 shows the end-of-month pool elevation. Data has been collected for Lake Oahe by the Corps of Engineers since 1959. The average pool elevation in the period of 1969 through present is 1607 feet msl Much fluctuation has occurred throughout the history of the reservoir. From 1969 to 1973, the reservoir's pool fluctuated from 1600.0 to 1617.0 feet msl. From 1973 to the flood of 1975, the pool elevation remained just above the top of the Carryover and Multiple Use pool (1607.5 feet msl). During 1975 Lake Oahe had a large inflow, pushing the pool just under the Exclusive Flood Control pool elevation. During the period from 1976 to 1977, the pool experienced a steady low around 1607.5 feet msl. In 1980 the pool began to drop until it reached a low of 1591 feet msl. During the period of 1982 to 1988 the pool elevation was again above the top of Carryover and Multiple Use pool elevation. Beginning in 1989, the reservoir began experiencing a drought which is continuing to cause lower-than-normal pool elevations (through 1992).

Thalweg Profile

Plate 62 shows the thalweg plot for the entire study reach. Analysis of the plot shows increases in elevation from 2 to 12 feet. This plot also shows significant sediment deposition at the mouth of the four major tributaries, the Cheyenne, Moreau, Grand, and Cannonball Rivers.

Average Bed Profile

A plot of the average bed elevation profile is presented on Plate 63. The results of the average bed elevation analysis generally show an increase in elevation from 2 to 6 feet for the 1958 to 1989 time period. Significant sediment deposition is apparent at the mouths of the four major tributaries.

Longitudinal Capacity Depletion (Volume by Segment)

Plates 64 through 66 show the reservoir volume by segment below elevation 1620 feet msl for the Missouri River portion of Lake Oahe for the 1958 and 1989 data. Downstream of RM 1315 until about RM 1196, a nearly constant amount of capacity depletion occurred between years 1958 and 1989. This decrease in volume is likely due to the sediment contributed by the multiple tributaries along that reach of the Missouri River. From RM 1196 to about RM 1148, almost no change is observed. Below RM 1148, capacity depletion is again apparent. This loss of volume likely took place when the reservoir began filling. The gross storage loss in Lake Oahe between 1958 and 1989 is 614,000 ac-ft (19,800 ac-ft/year), as shown on Plate 7.

D_{50} Bed Material Profile

Plates 67 through 69 show the D_{50} mechanical sieve analysis plot for grain size versus river mile. The curves shown on these plates reveal significant fluctuations in sediment size values. The primary trend represented on the curves is the grain size variation throughout the length of the reservoir.

The largest bed sediment material can be observed for year 1963 from RM 1192 to RM 1220. This likely reflects a location of higher flow velocities during the period the reservoir was being filled. It should be noted that the grain size distribution trend from RM 1280 upstream to RM 1332 is based on the 1954-55 sampling, which more likely represents the pre-dam condition of tributary deposition. A readily apparent trend upstream of RM 1280 is the gradual increase in grain size with distance upstream. This is probably the result of the settling characteristics of the inflowing sediment (larger particles settle first). The final observation from the bed material data is the presence of larger grain size in proximity to the confluence of each tributary with the Missouri River.

DEGRADATION REACH

The Oahe degradation reach (see range location map located on Plate 60) is covered by the Big Bend aggradation portion of the report. The only plot included herein is the tailwater trends plot.

TAILWATER RATING CURVE TRENDS

Plate 70 shows the tailwater trends for discharges of 10,000, 20,000, 30,000, 40,000, and 50,000 cfs. Tailwater data begins during 1972. From 1975 to 1982, the plot shows a steady decline in tailwater elevation. In 1982 an increase in elevation occurred until 1986. From 1986 to 1989 the tailwater elevation remained fairly constant. Since 1989 the trend appears to be towards a decreasing tailwater elevation. The net changes in tailwater for the period 1972 to 1992 are less than 0.5 feet.

BIG BEND PROJECT SEDIMENTATION CONDITIONS

DESCRIPTION OF PROJECT

Big Bend Dam is located at RM 987 of the Missouri River, near Fort Thompson and about 20 miles upstream from Chamberlain, South Dakota. The Big Bend Reservoir (Lake Sharpe) extends 80 miles upstream to the vicinity of the Oahe Dam. A range location map for the lake is shown on Plate 71. The project is basically a run-of-the-river power development with regulation of flows limited almost entirely to daily and weekly power operations. Construction began in 1959 with closure in July 1963. The first power unit was placed on line in October 1964 and the last of the eight units began operation during July 1966. Since full operation began, the reservoir has been held very near the normal operating level of elevation 1420. A maximum level at elevation 1421.9, very near the base of the exclusive flood control zone, occurred in 1971. Releases experienced from this project have been very similar to that described for Oahe with a maximum mean daily outflow of 69,200 cfs occurring during 1975. Releases have been entirely through the power plant since these facilities became fully operational. A mean daily release of zero is frequently made from the project, usually on a Sunday.

AGGRADATION REACH

End-of-Month Pool Elevation Records

Plate 72 shows the plot of the end-of-month pool elevations recorded by the Corps of Engineers since 1967. The Big Bend project reached its maximum normal operating pool elevation of 1420 feet msl in 1965. Lake Sharpe has a small amount of Carryover and Multiple Use storage space between elevations 1420 and 1422 feet msl, which is primarily a zone within which power generation benefits can be maximized by storage fluctuations that best enable the mainstem system as a whole to follow daily and weekly variations in power demand. Because of the small Carryover and Multiple Use storage, Lake Sharpe's change in pool elevation is virtually negligible.

Thalweg Profile

The thalweg profile plot (Plate 73) shows that aggradation begins near RM 1057 (near Farm Island), reaches a maximum change of nearly 17 feet near RM 1044, and then decreases downstream. From RM 1030 downstream, the profiles for each year are nearly parallel.

Average Bed Profile

Plate 74 presents the average bed profile plot for the Big Bend project. A common reference plane of 1,423 feet msl (Top of Exclusive Flood Control pool) was used. Similar in location and extent to the thalweg profile plot, the average bed shows a maximum change of nearly 10 feet near RM 1044.

Longitudinal Capacity Depletion (Volume by Segment)

Plates 75 through 77 present the water volume by segment (below elevation 1423 feet msl) for the Missouri River portion of Lake Sharpe for years 1956 and 1991. The greatest relative change of volume occurs just downstream of Farm Island (RM 1059.10). Deposition is apparent from Farm Island down to RM 1020 which corresponds to the location of the delta formation observed on the bed profile plots. The gross storage loss at Lake Sharpe since the orignal survey in 1956 is 140,000 ac-ft (4,000 ac-ft/year). The measured volume loss since closure of the dam in 1963 is 121,000 ac-ft (4,300 ac-ft/year), as shown on Plate 8.

D_{50} Bed Material Profile

Plate 78 shows an erratic series of D_{50} bed material grain size distribution curves for 1965, 1968, 1975, 1979. Just below the Oahe Dam at RM 1071.38 and RM 1069.68, larger particles in excess of 10 mm were sampled. This may be a result of degradation immediately downstream of the dam. Between RM 1069 and RM 1065, a noticeable decrease in the grain size distribution is observed. Grain size increases at the confluence of the Bad River and the Missouri River (RM 1065.19). Near RM 1059 (Farm Island) another jump in grain size occurs. From RM 1060 downstream the distribution flattens out and remains steady for all data obtained during the study reach years. This area is within the pool, where slower flow velocities allow the smaller particles to settle.

DEGRADATION REACH

The Big Bend project considers only the aggradation reach as the Fort Randall Reservoir extends to Big Bend Dam.

FORT RANDALL PROJECT SEDIMENTATION CONDITIONS

DESCRIPTION OF PROJECT

Fort Randall Dam is located at mile 880 of the Missouri River about 6 miles south of Lake Andes, South Dakota. The Fort Randall Reservoir (Lake Frances Case) extends to the Big Bend Dam. Plate 79 shows a range location map for the reservoir. Construction of the project was initiated in August 1946, closure was made in July 1952, initial power generation began in March 1954, and the project reached an essentially complete status in January 1956, when the eighth and final unit of the 320,000-kilowatt installation came into service. The maximum reservoir level experienced to date was in 1967 when an elevation of 1366.5 feet msl occurred, 1.5 feet above the base of the Exclusive Flood Control zone. The maximum mean daily release of 60,600 cfs was experienced in 1975.

AGGRADATION REACH

End-of-Month Pool Elevation Records

End-of-month pool elevations for Lake Francis Case have been recorded by the Corps of Engineers since the reservoir began to fill in January 1953. The pool elevation gaging station (designated as Gage 06452500 by the USGS) is located at RM 880.0 on the No. 6 tower of the Fort Randall Dam outlet works. Plots of the end-of-month pool elevations are presented on Plate 81. After closure in late 1952, the reservoir steadily filled until 1954. Power generation began with the first unit placed in service in March 1954 and the last on line by January 1956. Characteristics of the flood control function for the reservoir can be seen from 1956 onward with an annual fall-winter drawdown followed by a rapid rise in the spring months as flood runoff is accommodated. Between 1962 and 1971, at the end of the navigation season the pool elevation was drawn down to about elevation 1,320 feet msl. The drawdown was to make room for winter power releases from Lake Oahe and Big Bend. However, this operating practice was considered to have adverse economic effects and the practice from 1972 to the present is to limit the drawdown to about elevation 1,337.5 feet msl.

The peak pool elevation reached during a year, as a result of flood storage, is typically in the range of 1,355 to 1,364 feet msl. The peak end-of-month pool elevation during the period of record was 1,366.1 feet msl in June 1967. The facility began operation as a flood control project in the fall and winter of 1956 and 1957. The average pool elevation in the period 1957 through 1970 was 1,346.5 feet msl; 1971 corresponds to the end of the more severe drawdown era. Between 1971 and the present (1992), the average pool elevation has been approximately 1348.0 feet msl.

Thalweg Profile

Plate 82 shows the thalweg profile for Lake Francis Case. For the 60-mile Missouri River reach immediately upstream from Fort Randall Dam, an increase in elevation of between 10 and 25 feet is observed. These higher deposition depths result from the filling of the former stream channel. The results for the thalweg elevation between RM 930 and RM 955 reflect the presence of a delta formation from White River sediment inflow. Up to 40 feet of deposition has occurred in this delta reach. For the upstream reach of the reservoir, (upstream of RM 960), an increase in thalweg elevation between 10 and 25 feet is observed. The majority of this deposition took place prior to closure of Big Bend Dam.

Average Bed Profile

Plate 83 shows the average bed profile below the Top of Exclusive Flood Control pool elevation of 1365 feet msl from RM 884.05 to RM 986.90. The results of the average bed elevation analysis for the 60-mile Missouri River reach immediately upstream from Fort Randall Dam generally shows an increased elevation of between 5 and 10 feet from 1953 to 1986. Average bed elevation between RM 930 and RM 955 reflect the present delta formation from the White River sediment inflow, and it shows a maximum change of nearly 25 feet for the period of record. The impacts of limited sediment inflow quantities in the upstream reach of the Missouri River (upstream from RM 960) are shown on Plate 83. The average bed elevation increase from 1953 to 1986 is generally less than 5 feet, and mostly reflects materials deposited prior to closure of Big Bend Dam. For the last few miles of this reach (immediately downstream of Big Bend Dam), a small loss of material has occurred.

Longitudinal Capacity Depletion (Volume by Segment)

Plate 84 shows a plot of the reservoir water volume by segment below elevation 1380 feet msl for the Missouri River portion of Lake Francis Case for years 1953 and 1986. As expected, the largest depletion volumes occur downstream from RM 960. RM 955.86 corresponds to the confluence of the Missouri and White Rivers and the results reflect the White River being the primary source of sediments for the reservoir. Depletion has occurred for all segments between the dam and the White River. The gross storage loss for all of Lake Francis Case between the 1953 and 1986 surveys is 714,000 ac-ft (21,600 ac-ft/year) as shown on Plate 8.

D_{50} Bed Material Profile

Plate 85 shows the D_{50} grain size distribution for data collected in 1953, 1954, and 1981. Information to be gathered from this plot is limited due to the sparse number of points, however grain size does increase upstream from the dam.

DEGRADATION REACH

The Fort Randall degradation reach extends from Fort Randall Dam (RM 879.98) downstream 36 miles to just upstream of the confluence of the Niobrara River near RM 844. The only major tributary in this reach is Ponca Creek at RM 849. A range location map is shown on Plate 80.

Adjusted Water Surface Profile

Adjusted water surface profiles are plotted on Plate 86. These profiles were adjusted to a common discharge of 30,000 cfs. Two opposing trends occur within this reach. A trend of decreasing stage elevations has been occurring from Fort Randall Dam downstream to about RM 860, with the maximum decrease (about 5 feet) occurring immediately below the dam. Downstream of RM 860, river stages have increased both with time and with distance downstream. The maximum observed stage increase of 5 feet occurs at the confluence with the Niobrara River.

Between years 1954 and 1967, the trend reversal (from degrading to aggrading reach) occurred at about RM 869. For the two latest time periods of study, the trend reversal progressed in the downstream direction occurring at about RM 855 between years 1967 and 1975, and at about RM 852 between years 1975 and 1985.

Stage Trends

Plates 87 through 92 are plots of river stage elevation versus year for six gages below Fort Randall Dam. These gages are located at RM's 879.98, 865.04, 861.93, 853.37, 845.91, and 842.45. In general, the plotted stage trends match the trends observed for the adjusted water surface profiles, with the gages near the upstream and downstream ends of the reach (gages at RM 879.98 and RM 842.45) experiencing about 5 feet of degradation and aggradation respectively. The remainder of the gages are somewhat steady, reflecting their location with respect to the transition zone from a degrading to an aggrading reach.

Tailwater Rating Curve Trends

Plate 93 indicates that the Fort Randall Dam tailwater experienced a steady lowering trend in stage elevations over the full range of releases from 1953 to 1974 (nearly 5 feet total). Between 1974 and 1978, stages remained virtually unchanged. Following 1978, degradation resumed, but at a slower rate than the initial 21-year period. The total decrease in tailwater elevation for the period 1953 to 1991 is slightly less than 7 feet.

Thalweg Profile

Thalweg elevation profiles are shown on Plate 94. Considerable fluctuation in the thalweg is noted at nearly all cross-section locations. The only observable trend occurring is a slight lowering in elevation along a very short reach (4 miles) immediately downstream from Fort Randall Dam. Thalweg profiles of 1967 and 1975 are predominantly lower over the total river length, while profiles of 1952, 1962, and 1985 have much closer values, indicating a lack of any specific trend occurring through 1985.

Average Bed Profile

Plate 95 shows the average bed profiles for the Fort Randall degradation reach. Average bed elevations from Fort Randall Dam downstream to RM 860 show a lowering in the average bed elevation at all cross-section locations except at RM 868.0 (near Greenwood, South Dakota). Generally, the magnitude of lowering decreased in the downstream direction, with no trend indicated between RM 860 and RM 853. From RM 853 downstream to the Niobrara River aggradation has occurred with the exception of the cross-section at RM 850. The maximum increase in average bed elevation is nearly 10 feet, just upstream of the Niobrara River confluence.

Active Channel Width Profile

The top width at the adjusted water surface elevation (Plate 96) shows a channel widening trend at nearly all cross-section locations. Greatest changes occurred in the early period from 1952 to 1967 but the trend continued through 1985.

Channel Cross-Section Area Profile

Cross-section areas below the reference plane elevation, Plate 97, show a trend of increasing areas. Increases in this reach are smaller in the more recent time frame.

D_{50} Bed Material Profile

Plate 98 shows the D_{50} grain size distribution plots of the reach below Fort Randall Dam. A general trend toward coarser bed material is observed for the reach upstream of RM 854. This trend appears to have occurred in two separate cycles with the first cycle during the period 1954 to 1967 and the second cycle from 1975 to 1985. The coarsest bed material in the reach is found immediately below the dam, decreasing in size in the downstream direction (with the exception of the 10-mile reach between RM 853 and RM 863). This occurrence reflects the removal of finer sized sediments as the river tries to regain its full sediment load.

Cumulative Erosion

Plate 99 shows that cumulative erosion rates were highest during the period of 1953 to 1956 and progressively decreased through 1969. This decrease in erosion rates continued during the 1969 to 1974 period even though there were 25 months when flows were above average. Erosion rates dramatically increased during the years 1974 and 1975; a period of near-average discharge. This increase reflects the relocation of the thalweg during the 1969 to 1974 period to a more narrow flow-way configuration along easily erodible bankline. The 1976 to 1984 average erosion rate is similar to the low rate of 1969 to 1974.

GAVINS POINT PROJECT SEDIMENTATION CONDITIONS

DESCRIPTION OF PROJECT

Gavins Point Dam is located at RM 811.05 of the Missouri River, on the Nebraska-South Dakota border, 4 miles west of Yankton, South Dakota. The Gavins Point Reservoir (Lewis and Clark Lake) extends 37 miles to the vicinity of Niobrara, Nebraska. A range location map for the lake is shown on Plate 100. Construction was initiated in 1952, and closure was made in July 1955, with initial power generation beginning in September 1956. The third and final unit of the 100,000-kilowatt installation came into service in January 1957. Since full operation began, the reservoir has usually been regulated in the Flood Control and Multiple Use zone extending from elevation 1204.5 to elevation 1208 feet msl. A maximum level at elevation 1210.7 feet msl occurred in 1960. In 1969 the lake was drawn down to elevation 1199.8 feet msl in anticipation of large amounts of inflow from snowmelt. Minimum mean daily releases from the project have been about 5,000 cfs while maximum releases of 61,000 cfs were made in 1975.

AGGRADATION REACH

End-of-Month Pool Elevation Records

End-of-month pool elevations for Lewis and Clark Lake have been recorded by the Corps of Engineers since 1955. Plate 102 shows these pool elevations. For a typical year, 1971 to the present, the peak pool elevation (1208 feet msl) is reached during the summer months as a result of spring and early summer flood storage. Only one time in the reservoir's history did the pool elevation exceed the top of Exclusive Flood Control zone (1210.0 feet msl); this occurred in May 1960. The average pool elevation in the period 1963 through present is approximately 1207 feet msl.

Thalweg Profile

Plate 103 shows a series of erratic thalweg profiles. Upstream of RM 832, the thalweg elevation is highly variable, however when compared to original conditions, a general aggrading trend is observed. From downstream of RM 832 to the dam, a fairly steady rate of aggradation has occurred during the period of record, with an average net increase in thalweg elevation of 10 to 15 feet between 1955 and 1988. The maximum observed increase in elevation is approximately 26 feet near RM 827.

Average Bed Profile

Plate 104 shows the average bed profiles for all survey years. These profiles were developed using the maximum operating pool elevation of 1210 feet msl as the reference plane elevation. Upstream of RM 840, an erratic fluctuation of the average bed is shown with no definite trends. The observed deposition patterns and slopes between RM 840 and RM 830 would appear to correspond to the topset reach of the Lewis and Clark Lake delta. The increase in average bed elevation for the period of record for this reach is about 5 feet. Downstream of RM 830, the change in average bed elevation decreases rapidly, with little net change observed downstream of RM 820.

Longitudinal Capacity Depletion (Volume by Segment)

Plate 105 shows water volume by reservoir segment below pool elevation 1210 feet msl. These water volumes are 574,900 and 491,700 ac-ft for 1955 and 1985 respectively; a total difference of 83,200 ac-ft indicating an average sediment inflow rate of about 2,800 ac-ft/year. The largest volume change occurs between RM 837.5 and RM 832, which corresponds to the apparent location

of the delta topset reach. It should be noted that significant capacity depletion occurs beginning immediately upstream of the dam.

D_{50} Bed Material Profile

Plate 106 shows D_{50} bed material profiles for Lewis and Clark Lake. The 1955 data may be discounted as it most likely represents pre-dam conditions and is the only survey to cover the entire reach downstream of the Niobrara River. The coarsest material is found near RM 842, which is located just downstream of the Niobrara River confluence. Grain size decreases both upstream and downstream of this location. No temporal trends are readily apparent, due to the scarcity and highly variable nature of the data.

DEGRADATION REACH

The Gavins Point degradation reach extends from the Gavins Point Dam (RM 811.10) downstream 58 miles to RM 753.18. The major tributaries in this reach include the James River, located at RM 797.5, and the Vermillion River at RM 772.0. A range location map is presented on Plate 101.

Adjusted Water Surface Profile

Water surface profiles, adjusted to a common discharge of 30,000 cfs are plotted on Plate 107. Generally, decreasing stage elevations are noted from immediately below Gavins Point Dam throughout the remainder of the degradation reach. The greatest decreases in stage elevation over time occur from just below the dam and extend about 20 miles downstream to about RM 790. From RM 790 to RM 775, stage elevations continue to decrease, but the rate of change is less than the upstream reach. During the period from 1956 to 1965 the decreasing trend reverses at about RM 775, with a slight increase in water surface elevation for the remainder of the downstream reach.

Stage Trends

Three gages are located along the Missouri River in the study reach: Gayville (RM 796.00), Maskell (RM 775.8), and Ponca (RM 751.00). Plates 108 through 110 shows the stage trends for these gages. At the Gayville gage, the water surface dropped slightly (less than 0.5 feet) between 1955 and 1967. After 1967 until the last record in 1979, the drop was much more severe with nearly 3 feet of degradation observed. At the Maskell gage, the water surface dropped very slightly for all flow discharges between 1955-1967. From 1967 to 1972, stages decrease at a much greater rate for all discharges. After 1972 a general degradation trend is observed for 20,000, 30,000, and 40,000 cfs; however, at a rate slower than the previous 5 years. Plate 110 shows the stage trends for the Ponca gaging station. In general, stages have decreased with time at this location; however, the short period of record (six years) makes it difficult to draw any definite conclusions.

Tailwater Rating Curve Trends

Plate 111 shows the tailwater trends for 10,000, 20,000, and 35,000 cfs. Between 1956 and 1980, the tailwater declined steadily for all discharges for a total change of 7 to 8 feet. From 1980 to present, only a one to two foot decrease in tailwater elevation has been observed.

Thalweg Profile

Plate 112 shows the thalweg profile plots for the Gavins Point degradation reach. From RM 810 to RM 800 the thalweg has experienced a noticeable decrease in elevation (approximately 10 feet). For a 5-mile reach between RM 790 and RM 785, the thalweg profile has remained virtually unchanged for the period of record. From RM 785 downstream, the thalweg is

consistently lower than in previous years with nearly 10 feet of degradation occurring at some locations.

Average Bed Profile

Plate 113 represents the average bed elevations for 1959, 1965, 1974, and 1986. In general, the channel bed elevation degraded progressively with time for the entire study reach. The maximum degradation (10 feet) takes place immediately below the dam, although the rate of degradation decreased with time in this area. Between RM 807 and RM 790, the temporal change in bed elevation was almost constant between the years 1959 and 1986. Downstream of this reach the profiles are somewhat more variable with increases in average bed elevation at some locations for some time periods.

Active Channel Width Profile

The longitudinal change in cross-section width for the Gavins Point reach is shown on Plate 114. From this plot, the upstream cross-sections from RM 810 to RM 795 show an overall decrease in cross-section width. Between RM 794 and RM 776 the cross-section width has changed little from survey to survey, although a general decrease in width is apparent. From RM 776 downstream a large fluctuation between survey years is observed, but the trend seems to be a noticeable reduction in the cross-section width.

Channel Cross-Section Area Profile

The time variations of cross-section area versus river mile for the entire study reach is shown on Plate 115. The plot shows a loss of cross-sectional area in comparison to the earlier surveys (1959 and 1965) upstream of RM 775; however, an increase in cross-section area is observed for the period 1974 to 1986. Downstream of RM 775 the profiles fluctuate significantly with no observed temporal trends.

D_{50} Bed Material Profile

Plate 116 shows the D_{50} bed material grain size distribution. Immediately downstream from Gavins Point Dam to about RM 795, a significant progressive trend of the coarsening of the bed material with time is observed. As an example, the median bed material size in this reach increased from about 0.4 mm to about 10 mm at certain locations. Downstream from RM 795, no historical or spatial trends can be determined. In this same reach the bed material is coarsest immediately downstream of the dam, generally becoming less coarse with distance downstream.

Cumulative Erosion

Plate 117 shows the cumulative erosion with time. The average annual rate of erosion for the entire study reach was about 172 ac-ft/year. In general, the bank erosion rate was slightly greater for the period before closure of the dam (approximately 202 acre-feet/year).

MISSOURI RIVER MAINSTEM RESERVOIR WATER QUALITY CONDITIONS

BACKGROUND

The Omaha District maintains a water quality monitoring program for each lake in its geographic boundary for meeting the following objectives:

a. Insure the impounded waters and releases from each lake project are of suitable quality for the established project uses.

b. Establish base line conditions by defining pre-project (pre-impoundment) and post-project water quality conditions at each lake project.

c. Determine if project waters are in compliance with applicable State and Federal water quality standards.

d. Quantitatively identify and assess the magnitude of existing and potential water quality problems associated with project waters. Detect changes over time which may be either beneficial or degrading.

e. Study special problems or develop criteria for such solutions as structural modification or modification of reservoir regulation procedures aimed at controlling or enhancing environmental conditions and meeting water quality objectives.

f. Provide an understanding of project conditions to facilitate coordination with state agencies in regard to implementing watershed pollution control.

Three types of investigations are performed on reservoir projects: 1) pre-impoundment; 2) surveillance; and 3) comprehensive investigations. A pre-impoundment investigation is made before completion of a project to establish baseline conditions. A surveillance investigation is an annual post-project investigation consisting of fixed-station sample collection and analysis of basic water quality parameters to establish water quality trends. A comprehensive investigation is an extensive post-project investigation conducted as several locations in the lake to obtain a more thorough understanding of reservoir water quality. Additional water quality parameters are analyzed if a specific problem is being investigated and to obtain a comprehensive evaluation of the present project conditions.

PRE-IMPOUNDMENT INVESTIGATIONS

The Missouri River mainstem reservoir system went into operation prior to the existence of a Corps of Engineers water quality program. Therefore, pre-impoundment investigations were not undertaken.

SURVEILLANCE INVESTIGATIONS

As part of its routine surveillance program, the Omaha District collects water samples at its reservoirs and releases six times per year unless this data is available from other sources. Plates 125 through 130 show the sampling location for each Missouri River mainstem reservoir. Routine coordination of sample collection and analyses is conducted with other agencies within the Omaha District to avoid duplication of sampling effort. Inflows to reservoirs are sampled only when data are not available from other sources. Stream data for several project inflows are collected by the U.S. Geological Survey under their programs and are assessable through the Environmental Protection Agency's computer database, STORET. The Omaha District also stores all of its data on STORET.

Continually recording monitors are located at the mainstem dams to monitor the dissolved oxygen and temperature of the reservoir releases. These release water quality monitors are being replaced with new monitors that allow access to the data via a phone modem for data downloading and real time monitoring of the releases for dissolved oxygen, conductivity, pH, and temperature.

The types of chemical analyses performed are established on a state and project basis since standards may differ among states and projects. These analyses are conducted to determine compliance with state and local water quality standards, determine compliance with Federal criteria, identify water quality problems, and attempt to provide a characterization of reservoir water quality.

COMPREHENSIVE INVESTIGATIONS

Reservoir Water Quality Surveys

Reservoir water quality surveys are periodically conducted to assess the sampling adequacy of the larger, and more complex, reservoirs. This is required because, as part of the District's basic program, water samples are collected from only two location on the larger reservoirs. The morphometry of the mainstem reservoirs results in considerable variation in water quality between sampling points. The amount of variation and, therefore, the adequacy of the routine sampling program, is evaluated through a reservoir survey. During the survey, samples are collected in numerous locations throughout the reservoir. Comparison of the results of these sample analyses indicates the water quality variance throughout the reservoir. These data assist in interpreting the limited data available through the District's basic water quality sampling program. In addition, these surveys aid in identifying problems that the routine sampling program may miss.

Special Studies

Special studies are conducted to determine the extent of identified problems or to resolve problems. Examples of these studies conducted in recent years include: 1) sediment sample collection to determine potential lead contamination related to maintenance activities at Fort Peck Dam; 2) sampling and analysis concerning an algal toxin problem at the Fort Peck Pines Youth Camp; 3) an investigation which discovered a faulty treatment plant discharging raw sewage into Lewis and Clark Lake; and 4) sediment sampling at Lewis and Clark Lake in conjunction with construction of island habitat for endangered terns and threatened plovers. A special studies investigation completed during 1992 explored water quality impacts of resuspending metal-laden sediments during pool drawdown periods. This special study is discussed in detail in the section entitled "Delta Sediment Chemistry".

WATER QUALITY PROBLEMS

Water quality problems within the Omaha District mainstem reservoir system are due to many factors including diffuse contaminants; agricultural practices; mining, coal, and oil development; sewage treatment problems; and sediment and nutrient inputs to the lake. Table 2 summarizes water quality problems and issues for the Missouri River mainstem lakes. A more detailed discussion of the significant water quality problems follows.

Pesticides

Agricultural practices, both past and present, include the application of pesticides throughout much of the Missouri River basin. Pesticides detected in recent years include chlordane, atrazine, alachlor, diazinon, dacthal, benzene hexachloride, metolachlor, dieldrin, DDT, simazine,

WATER QUALITY PROBLEMS AND ISSUES

Project	Algal Blooms	Fish Kills	Potential Problem Areas (*)	EPA Ambient Water Quality Criteria: Exceedances	State Standard Exceedance
Fort Peck, Montana	No	No	Coal and Oil Development, Algal Blooms, Diazinon	**INFLOWS:** arsenic, sulfate, pH, mercury, dissolved oxygen, beryllium, manganese, iron. **RESERVOIR:** arsenic, iron, dissolved oxygen, pH. **RELEASES:** arsenic, pH	**INFLOWS:** none identified. **RESERVOIR:** dissolved oxygen, pH. **RELEASES:** dissolved oxygen.
Lake Sakakawea, North Dakota	Yes	No	Oil Drilling, Strip Mining, Algal Blooms, Low Dissolved Oxygen, Atrazine	**INFLOWS:** arsenic, mercury, sulfate. **RESERVOIR:** arsenic, mercury, dissolved oxygen, iron, lead, sulfate, nitrate, copper. **RELEASES:** arsenic, mercury.	**INFLOWS:** sulfate, unionized ammonia. **RESERVOIR:** pH, dissolved oxygen, sulfate. **RELEASES:** unionized ammonia.
Lake Oahe, South Dakota	No	No	Agricultural Runoff Containing Pesticides and Other Contaminants, Bioaccumulation of Mercury, Diazinon	**INFLOWS:** arsenic, sulfate, manganese, mercury, iron, beryllium. **RESERVOIR:** arsenic, sulfate, dissolved oxygen, pH, iron, lead, manganese, copper. **RELEASES:** sulfate.	**INFLOWS:** pH, sulfate, fecal coliform bacteria, unionized ammonia. **RESERVOIR:** dissolved oxygen, pH, suspended solids, lead. **RELEASES:** pH.
Lake Sharpe, South Dakota	No	No	Agricultural Runoff Containing Pesticides and Nutrients Diazinon	**INFLOWS:** sulfate. **RESERVOIR:** dissolved oxygen, sulfate, arsenic. **RELEASES:** arsenic, lead, sulfate.	**INFLOWS:** pH, suspended solids. **RESERVOIR:** dissolved oxygen, pH. **RELEASES:** none identified.
Lake Francis Case, South Dakota	No	No	Intrusion of the White River Delta Metolachlor Alachlor Diazinon	**INFLOWS:** arsenic, sulfate. **RESERVOIR:** arsenic, iron, mercury, lead, sulfate, manganese, pH. **RELEASES:** arsenic, lead, sulfate.	**INFLOWS:** pH, suspended solids. RESERVOIR: pH. RELEASES: pH.
Lewis and Clark, South Dakota	Yes	Yes	Emergent Aquatic Vegetation Inadequate Sewage Treatment Diazinon	**INFLOWS:** arsenic, mercury, lead, sulfate, pH. **RESERVOIR:** iron, pH, sulfate, mercury, lead, manganese, arsenic. **RELEASES:** iron, sulfate, manganese, arsenic, pH.	**INFLOWS:** mercury, pH, lead. **RESERVOIR:** pH, mercury, lead, silver. **RELEASES:** pH, silver.

Table 2

* This column contains pesticides detected in project waters for which state or federal standards have not been developed.

metribuzin, and propachlor. Detecting several pesticides in a single sampling trip is not unusual.

Due to the widespread occurrence of pesticides, bioaccumulation of some pesticides in tissue of aquatic organisms is a potential threat to all consumers of these organisms. Fish were collected by the Nebraska Department of Environmental Control in Lewis and Clark Lake in 1988. The tissue contained cadmium, mercury, and DDT; however, all were below Food and Drug Administration (FDA) action levels. Periodic monitoring of the fish tissue in projects will be essential for protection of consumer health.

Mercury

Mercury is a diffuse contaminant ubiquitous in the Omaha District. It was contributed to Lake Oahe from mining operations within the Cheyenne River sub-basin in South Dakota. Gold was extracted from the ore with mercury at the Homestake Gold Mine. This point source of mercury has resulted in the contamination of the Cheyenne River and the Cheyenne Arm of Lake Oahe. While the source of contamination has been controlled, the Cheyenne River sediments remain contaminated and continue to be deposited into the Cheyenne Arm.

Low Dissolved Oxygen

Low dissolved oxygen concentrations are typically the result of the impoundment or of reservoir operation. Operational controls to alleviate this problem are limited within the Omaha District as most projects were not constructed with multiple level outlets. Low dissolved oxygen concentrations may result in an influx of metals such as iron and manganese from the bed sediments into the water column. These concentrations may be 10 to 1,000 times higher than normal concentrations and may result in detrimental effects to water users. Low in-lake oxygen concentrations can also result in releases which are detrimental to downstream fisheries.

Low dissolved oxygen levels have been observed to occur at Lake Sakakawea under conditions of lower lake levels. The hypolimnetic volume decreases as lake levels decrease. The oxygen demand exerted by the bottom sediment and in-lake organic matter further reduces the hypolimnetic oxygen. As a result, reservoir fisheries may be damaged by the low dissolved oxygen levels. Although the hypolimnetic dissolved oxygen levels may fall below state standards, the releases from Garrison Dam have not violated state dissolved oxygen standards.

Dissolved oxygen problems similar to those at Lake Sakakawea have been observed at Lake Oahe.

Mineral Development

Mineral development activities threatening lake water quality are strip mining in North Dakota and extensive oil exploration in Montana, North Dakota, and South Dakota. The effects of these activities are particularly evident in Lake Sakakawea where a brine spill (associated with oil drilling) occurred in 1989 and toxic waste storage ponds were discovered on COE property (leased by the Flying J Oil Company) near Williston, North Dakota, in 1985. No damage to water quality was detected as a result of the brine spill. The Flying J's waste storage ponds were sealed and a post closure monitoring program implemented. The program will determine the effectiveness of the seal by monitoring groundwater for leakage for up to 30 years.

DELTA SEDIMENT CHEMISTRY: LAKES OAHE, SAKAKAWEA AND FORT PECK

PURPOSE

The purpose of this sampling and subsequent analysis is to test the hypothesis that changing the reservoir pool elevations will result in sediment resuspension thus potentially adding contaminants to the reservoir thus degrading water quality. This problem was proposed by members of the Missouri Basin States Association (MBSA) subcommittee. In addition to providing insights pertinent to sediment resuspension, this study will produce sediment chemistry data which is nearly non-existent on the mainstem system.

METHODS AND MATERIALS

Approximate delta sediment sampling locations were selected by analyzing aggradation reach thalweg profiles for Fort Peck Lake, Lake Sakakawea, Lake Oahe, and associated tributaries. Generally, samples were obtained in the topset, foreset, and botttomset areas of the delta, see Plate 9 for area location. A fourth sample was obtained approximately 10 miles downstream of the delta since severe drought conditions could result in the reservoir headwaters being located below the existing delta. Sampled tributary locations were selected using the above method, however, since tributary deltas are small, only one or two sampling locations were selected for each delta. The Oahe delta was sampled in only a single location since thalweg profiles show little in terms of normal delta formation. It appears that the Lake Oahe delta area has undergone periods of aggradation and degradation associated with pool elevation variations. All samples were obtained from the thalweg area unless there was evidence of scouring flows (Lake Oahe), in which cases samples were taken from an inundated area other than the thalweg. In addition, a sample from a nearby area which was not inundated was obtained to assess parameter background levels. Sampling locations, in 1960 river miles, are shown on Table 3 while aggradation reach thalweg profiles are shown in Plates 118 through 124. Map location of sampling are shown in Plates 125 through 130.

Sediment samples were obtained using a stainless steel Ponar dredge. Samples were placed in a plastic container for shipment to the North Dakota State Department of Health and Consolidated Laboratories for analysis. Overburden water samples for the elutriate testing were taking using a Kemmerer sampler. Composite samples were not taken since stratification would not normally occur in the delta area. These samples were placed in plastic containers, iced and shipped to the North Dakota Department of Health and Consolidated Laboratories for analysis.

Sampled parameters include mercury, cadmium, lead, chromium, zinc, selenium, arsenic, nickel, pesticides, etc., (Tables 4 and 5). Particle size analyses were also conducted since finer sediments tend to be more chemically active and particle size data may provide valuable information on future sampling optimization. Chemical analysis was done using EPA approved methods and the elutriated procedure was conducted using documentation provided in the EPA/COE Technical Committee Criteria for Dredged and Fill Material. The elutriate test was chosen since it would most closely approximate resuspension and settling which would occur as a result of wind-wave action under natural conditions.

RESULTS AND DISCUSSION

Results of elutriate testing are shown in Tables 4 and 5. Overbank data, samples which were never inundated, are also shown in Tables 4 and 5. Overbank samples are shown for comparative purposes since the source of metals etc., is the watershed. Mean surface water values for the period of record also shown for comparative purposes are contained in Tables 6 and 7.

TABLE 3

ELUTRIATE AND RAW WATER ARSENIC DATA FOR MAINSTEM RESERVOIRS

Location River Miles (1960)	Raw Water Value ug/l	Elutriate Value ug/l	Difference ug/l	Particle Size sand %	silt %	clay %
Fort Peck Ambient water values for arsenic ranged from 0.0-240 ug/l for the period 1976-1991. A single overbank arsenic value taken at river mile 1880 was 4,820 ug/l.						
1805	3.6	43.6	+40.0	0.8	45.2	54.0
1820	4.3	25.5	+21.2	1.0	35.6	63.4
1840	4.6	51.1	+46.5	0.8	44.8	54.4
1878	7.0	2.6	- 4.4	8.6	30.5	60.9
Little Missouri Ambient water values for arsenic ranged from 1.0-240 ug/l for the period 1974-1981. A single overbank arsenic value taken at river mile 35 was 14,900 ug/l.						
0	2.0	6.8	+ 4.8	2.1	18.4	79.5
7	2.3	4.3	+ 2.0	2.0	31.0	67.0
15	1.9	1.6	- 0.3	21.5	65.2	13.3
38.5	7.4	2.0	- 6.4	84.2	15.0	00.0
Lake Sakakawea Ambient water values for arsenic ranged from 1.0-8.0 ug/l for the period 1974-1991.						
1480	3.6	7.2	+3.6	4.6	52.5	42.9
1510	3.0	6.1	+3.1	0.4	23.9	75.7
1520	9.2	1.2	-8.0	67.2	30.7	2.1
1530	3.8	2.7	-1.1	0.8	27.9	71.3
Cheyenne Ambient water values for arsenic ranged from 1.0-230 ug/l for the period 1974-1985.						
12	2.9	10.2	+7.3	0.2	26.6	73.2
30	43.5	2.5	-41.0	95.8		3.6
Oahe Ambient water values for arsenic ranged from 1.0-8.0 for the period 1976-1990.						
1232	2.1	3.8	+1.7	5.0	40.1	54.9
Moreau Ambient water values for arsenic ranged from 1.0-29.0 ug/l for the period 1976-1982.						
5	1.8	4.3	+2.5	2.6	29.0	68.4
Grand Ambient water values for arsenic ranged from 1.0-16.0 ug/l for the period 1975-1982.						
10	1.6	5.5	+3.9	0.2	25.2	74.6

TABLE 4

WATER, SEDIMENT AND ELUTRIATE DATA FROM MISSOURI RIVER, TRIBUTARIES AND MAINSTEM DAMS

LOCATION	MEDIUM	UNITS	GS ID #	VALUE IN ug/L OR ug/g COPPER	ZINC	BARIUM	CHROMIUM	ARSENIC	SELENIUM	CADMIUM	LEAD
FORT PECK 1805	WATER	PPB	92-C392	<14	71	66.8	0.25	3.6	<1	<0.2	1.3
FORT PECK 1805	SEDIMENT	PPM	92-C396	5.69	18.5	26.3	1.22	3.31	0.107	0.063	4.22
FORT PECK 1805	ELUTRIATE	PPB	92-C398	<14	21	75	<0.2	43.6	1	<0.2	1.0
FORT PECK 1820	WATER	PPB	92-C390	50	69	42.7	<0.2	4.3	2	<0.2	1.3
FORT PECK 1820	SEDIMENT	PPM	92-C395	6.04	21.5	31	1.66	4.18	0.109	0.074	5.16
FORT PECK 1820	ELUTRIATE	PPB	92-C401	<14	18	78.6	1.01	25.5	1	<0.2	0.9
FORT PECK 1840	WATER	PPB	92-C391	<14	86	50.2	<0.2	4.6	2	<0.2	3
FORT PECK 1840	SEDIMENT	PPM	92-C397	7.23	24	35.6	3.7	3.71	0.153	0.116	5.99
FORT PECK 1840	ELUTRIATE	PPB	92-C399	<14	25	82.8	0.45	51.1	3	<0.2	0.7
FORT PECK 1880	WATER	PPB	92-C389	20800	140	129	6.48	7.0	3	0.36	9.3
FORT PECK 1880	SEDIMENT	PPM	92-C394	10.7	50.5	78.6	8.96	7.4	0.17	0.94	9.53
FORT PECK 1880	ELUTRIATE	PPB	92-C400	<14	22	79	0.89	2.6	3	<0.2	1.2
FORT PECK 1880 OVERBANK	SEDIMENT	PPM	92-C393	12.8	61.8	47.9	23.9	4.82	0.264	0.135	12.3
FORT PECK 1880 OVERBANK	ELUTRIATE	PPB	92-C497	<14	317	36.7	1.19	1.4	1	3.64	0.8
LITTLE MISSOURI 0	WATER	PPB	92-C315	<14	45	50	<0.2	2.0	<1	<0.2	2.3
LITTLE MISSOURI 0	SEDIMENT	PPM	92-C337	6.86	16.8	28.8	34.4	2.16	0.098	0.101	3.76
LITTLE MISSOURI 0	ELUTRIATE	PPB	92-C326	<14	11	90.4	<0.2	6.8	2	<0.2	1.0
LITTLE MISSOURI 7A	WATER	PPB	92-C317	<14	46	53.1	<0.2	2.3	<1	0.21	1.9
LITTLE MISSOURI 7A	SEDIMENT	PPM	92-C335	6.16	18.2	43.8	3.91	1.64	0.123	0.1	4.39
LITTLE MISSOURI 7A	ELUTRIATE	PPB	92-C329	<14	11	93.1	<0.2	4.3	1	<0.2	0.9
LITTLE MISSOURI 15	WATER	PPB	92-C313	<14	47	49.6	0.78	1.9	4	<0.2	2.2
LITTLE MISSOURI 15	SEDIMENT	PPM	92-C338	10.6	24.1	122	6.42	4.43	0.063	0.142	5.16
LITTLE MISSOURI 15	ELUTRIATE	PPB	92-C327	<14	20	65.5	<0.2	1.6	3	<0.2	2.2
LITTLE MISSOURI 35	WATER	PPB	92-C319	181	610	1000	80.1	7.4	1	2.92	123
LITTLE MISSOURI 35	SEDIMENT	PPM	92-C330	6.23	23.1	67.8	7.28	2.54	0.047	0.113	5.04
LITTLE MISSOURI 35	ELUTRIATE	PPB	92-C321	<14	12	73.8	1.15	2.0	4	<0.2	1.9
LITTLE MISSOURI 35 OVERBANK	SEDIMENT	PPM	92-C331	29.4	67	40.8	21	14.9	0.268	0.53	14
LITTLE MISSOURI 35 OVERBANK	ELUTRIATE	PPB	92-C322	<14	<9	6.64	0.86	2.8	51	0.91	0.6
LAKE SAKAKAWEA 1480	WATER	PPB	92-C320	<14	58	56.2	2.14	3.6	1	0.3	7.8
LAKE SAKAKAWEA 1480	SEDIMENT	PPM	92-C336	8.13	26	67.1	5.64	1.78	0.09	0.14	5.52
LAKE SAKAKAWEA 1480	ELUTRIATE	PPB	92-C328	<14	11	95.9	<0.2	7.2	2	<0.2	0.8
LAKE SAKAKAWEA 1510	WATER	PPB	92-C316	<14	38	55.4	2.28	3.0	<1	<0.2	3.5
LAKE SAKAKAWEA 1510	SEDIMENT	PPM	92-C332	7.05	24	45.6	4.89	2.66	0.1	0.116	5.98
LAKE SAKAKAWEA 1510	ELUTRIATE	PPB	92-C324	<14	12	120	<0.2	6.1	<1	<0.2	1.1
LAKE SAKAKAWEA 1520	WATER	PPB	92-C318	<14	105	164	11.5	9.2	1	0.32	13.7
LAKE SAKAKAWEA 1520	SEDIMENT	PPM	92-C333	2.83	19	62.5	3.42	3.03	0.028	0.064	4.26
LAKE SAKAKAWEA 1520	ELUTRIATE	PPB	92-C323	<14	14	46.1	<0.2	1.2	<1	0.26	1.7
LAKE SAKAKAWEA 1530	WATER	PPB	92-C314	<14	58	92.3	5.99	3.8	2	0.52	6.5
LAKE SAKAKAWEA 1530	SEDIMENT	PPM	92-C334	16.1	16.5	124	12.7	3.82	0.216	0.428	20.2
LAKE SAKAKAWEA 1530	ELUTRIATE	PPB	92-C325	<14	16	98.5	<0.2	2.7	<1	<0.2	3.8
CHEYENNE DELTA 12	WATER	PPB	92-C456	<14	84	44.9	<0.2	2.9	2	<0.2	2.5
CHEYENNE DELTA 12	SEDIMENT	PPM	92-C462	3.12	11.7	32	3.35	2.31	0.04	0.06	3.73
CHEYENNE DELTA 12	ELUTRIATE	PPB	92-C463	<14	17	81.9	0.69	10.2	1	0.56	1
CHEYENNE DELTA 30	WATER	PPB	92-C457	60	428	1030	45.3	43.5	3	0.72	57.5
CHEYENNE DELTA 30	SEDIMENT	PPM	92-C464	1.83	12.9	51.7	1.15	6.5	0.065	0.048	2.82
CHEYENNE DELTA 30	ELUTRIATE	PPB	92-C465	<14	18	89.7	0.43	2.5	3	<0.2	1.1
CHEYENNE DELTA 30 OVERBANK	SEDIMENT	PPM	92-C461	NO ANALYSIS							
CHEYENNE DELTA 30 OVERBANK	ELUTRIATE	PPB	92-C489	<14	104	71	6.09	3.4	1	<0.2	2
LAKE OAHE 1232	WATER	PPB	92-C459	<14	83	66.3	0.94	2.1	2	<0.2	3.5
LAKE OAHE 1232	SEDIMENT	PPM	92-C468	7.04	20.7	50.1	23.2	2.23	0.124	0.156	4.99
LAKE OAHE 1232	ELUTRIATE	PPB	92-C469	<14	34	113	0.35	3.8	1	<0.2	0.5
MOREAN DELTA 5	WATER	PPB	92-C458	<14	135	47.4	1.56	1.8	1	<0.2	1.7
MOREAN DELTA	SEDIMENT	PPM	92-C466	5.77	22.8	65.1	4.13	1.26	0.215	0.066	4.58
MOREAN DELTA	ELUTRIATE	PPB	92-C467	<14	10	84.1	<0.2	4.3	1	<0.2	1.1
GRAND R DELTA 10	WATER	PPB	92-C460	<14	99	46.8	0.86	1.6	3	<0.2	2.4
GRAND R DELTA 10	SEDIMENT	PPM	92-C470	6.18	20.4	35.6	4.68	1.79	0.154	0.091	4.87
GRAND R DELTA 10	ELUTRIATE	PPB	92-C471	<14	34	150	0.47	5.5	2	<0.2	0.4

TABLE 5

WATER, SEDIMENT AND ELUTRIATE DATA FROM THE MISSOURI RIVER, TRIBUTARIES AND MAINSTEM DAMS

VALUES IN mg/L or umhos/cm

LOCATION	MEDIUM	GS ID #	Na	Mg	K	Ca	Mn	Fe	Cl-	NH3 as N	pH	CO3	HCO3	TOT ALK	Cond	P total	SO4	NO3+NO2	TKN	HARDNES	TDS
FORT PECK 1805	WATER	92-C392	42.3	23.3	3.22	56.4	0.004	0.108	8.5	0.01	8.24	0	191	156	562	0.025	121	0.007	0.24	237	349
FORT PECK 1805	SEDIMENT	92-C396																			
FORT PECK 1805	ELUTRIATE	92-C398	32.6	17.7	5.47	44.5	1.29	0.01	9.3	2.71	7.6	0	226	185	599	0.04	113	0.022	3.1	184	334
FORT PECK 1820	WATER	92-C390	39	22.2	3.47	55.9	0.005	0.167	8.6	0.005	8.15	0	189	155	547	0.014	109	0.016	0.19	231	331
FORT PECK 1820	SEDIMENT	92-C395																			
FORT PECK 1820	ELUTRIATE	92-C401	41.4	22.5	7.33	54.8	2.39	0	9.4	4.06	7.86	0	245	201	611	0.023	108	0.025	3.81	230	364
FORT PECK 1840	WATER	92-C391	40.7	22.3	3.27	54.8	0.012	0.192	9	0.005	8.24	0	184	151	546	0.024	118	0.015	0.27	229	339
FORT PECK 1840	SEDIMENT	92-C397																			
FORT PECK 1840	ELUTRIATE	92-C399	52.7	19.9	4.5	50.1	1.31	0.083	12.2	3.4	7.93	0	227	186	752	0.035	185	0.013	2.49	207	436
FORT PECK 1880	WATER	92-C389	39.5	22.9	3.9	55.9	0.122	6.14	9.6	0.022	8.14	0	187	153	547	0.279	118	0.017	0.23	234	342
FORT PECK 1880	SEDIMENT	92-C394																			
FORT PECK 1880	ELUTRIATE	92-C400	35.3	18.8	3.93	52.1	0.445	0.031	9	0.928	7.69	0	214	175	610	0.013	133	0.009	0.9	208	358
FORT PECK 1880 OVERBANK	SEDIMENT	92-C393																			
FORT PECK 1880 OVERBANK	ELUTRIATE	92-C497	132	76.1	26.9	264	3.9	0.076	1.6	0.881	4.05	0	0	0	2231	0.042	1300	0.362	1.45	973	1800
LITTLE MISSOURI 0	WATER	92-C315	57.4	20.7	4.2	52.3	0.003	0.035	10	0	8.48	7	169	150	619	0.005	164	0.045	0.32	216	399
LITTLE MISSOURI 0	SEDIMENT	92-C337																			
LITTLE MISSOURI 0	ELUTRIATE	92-C326	64.7	18.6	6.83	45.2	1.46	0.014	9	2.07	7.7	0	230	188	648	0.019	138	0.012	2.72	190	396
LITTLE MISSOURI 7A	WATER	92-C317	73.5	22.7	4.3	54.1	0.012	0.169	9.7	0	8.09	0	198	162	687	0.022	180	0.065	0.37	229	442
LITTLE MISSOURI 7A	SEDIMENT	92-C335																			
LITTLE MISSOURI 7A	ELUTRIATE	92-C329	74.6	19	6.8	49.2	1.36	0.017	9.3	1.44	7.31	0	213	174	694	0.021	161	0.013	1.92	201	425
LITTLE MISSOURI 15	WATER	92-C313	140	18.7	5.1	46	0.017	0.611	8.6	0	8.57	10	208	187	898	0.039	267	0.296	0.56	192	598
LITTLE MISSOURI 15	SEDIMENT	92-C338																			
LITTLE MISSOURI 15	ELUTRIATE	92-C327	132	21.8	4.83	49.3	0.034	0.007	8.6	0.2	9.06	0	232	190	923	0.033	250	0.277	0.72	213	581
LITTLE MISSOURI 35	WATER	92-C319	254	76.4	16.9	173	4.62	99.5	12.5	0.075	8.49	10	595	504	1565	5.89	596	0.596	1.47	747	1430
LITTLE MISSOURI 35	SEDIMENT	92-C330																			
LITTLE MISSOURI 35	ELUTRIATE	92-C321	335	12.3	8.5	30.3	0.003	0.135	7.9	0.343	8.35	9	311	270	1586	0.02	515	1.07	1.43	126	1070
LITTLE MISSOURI 35 OVERBANK	SEDIMENT	92-C331																			
LITTLE MISSOURI 35 OVERBANK	ELUTRIATE	92-C322	1140	192	22.5	352	0.123	0.012	3.9	0.778	7.59	0	79	65	5904	0.028	3760	3.02	1.53	1670	5510
LAKE SAKAKAWEA 1480	WATER	92-C320	39.9	17	4.1	45.2	0.039	1.54	6.6	0	8.12	0	144	118	457	0.034	103	0.194	0.43	183	286
LAKE SAKAKAWEA 1480	SEDIMENT	92-C336																			
LAKE SAKAKAWEA 1480	ELUTRIATE	92-C328	40.9	15.5	4.73	40.8	1.32	0.029	6.7	1.46	7.7	0	168	138	502	0.028	99	0.047	2.08	165	290
LAKE SAKAKAWEA 1510	WATER	92-C316	36.3	14.2	3.2	38.1	0.026	1.7	5.4	0	8.22	0	128	105	412	0.095	91	0.258	0.27	154	251
LAKE SAKAKAWEA 1510	SEDIMENT	92-C332																			
LAKE SAKAKAWEA 1510	ELUTRIATE	92-C324	41.9	20.9	5.07	56.2	1.15	0.011	6	1.94	7.88	0	250	205	576	0.016	79	0.041	2.55	227	332
LAKE SAKAKAWEA 1520	WATER	92-C318	32.7	19.9	5.1	50.3	0.398	16.4	7.9	0.009	8.02	0	138	113	418	0.542	122	0.177	0.29	208	306
LAKE SAKAKAWEA 1520	SEDIMENT	92-C333																			
LAKE SAKAKAWEA 1520	ELUTRIATE	92-C323	32.8	14.9	2.53	39.8	0.001	0.015	5.3	0.08	8.06	0	141	115	437	0.023	90	0.759	0.447	161	255
LAKE SAKAKAWEA 1530	WATER	92-C314	35.7	16.2	4.1	45.3	0.192	4.9	4.5	0	8.17	0	160	131	455	0.149	98	0.047	0.42	180	283
LAKE SAKAKAWEA 1530	SEDIMENT	92-C334																			
LAKE SAKAKAWEA 1530	ELUTRIATE	92-C325	72.1	16.3	8	42.2	0.025	0.86	6.4	0.085	8.03	0	203	166	595	0.136	137	0.211	0.577	173	382
CHEYENNE DELTA 12	WATER	92-C456	71.4	21.7	4.02	56.8	0.014	0.134	13	0.016	7.43	6	175	153	763	0	224	0.032	0.52	231	483
CHEYENNE DELTA 12	SEDIMENT	92-C462																			
CHEYENNE DELTA 12	ELUTRIATE	92-C463	102	24.2	10.6	87.3	1.23	0	14.2	0.814	7.83	0	298	244	941	0.033	238	0.014	1.96	318	623
CHEYENNE DELTA 30	WATER	92-C457	211	62	12.7	176	2.24	66.6	57.9	0.051	8.26	0	175	143	1845	2.25	797	0.074	0.31	695	1400
CHEYENNE DELTA 30	SEDIMENT	92-C464																			
CHEYENNE DELTA 30	ELUTRIATE	92-C465	196	62.1	1.34	176	0.003	0	56.2	0.001	7.89	0	123	101	1819	0.025	816	0	0.91	696	1380
CHEYENNE DELTA 30 OVERBANK	SEDIMENT	92-C461	No Analysis																		
CHEYENNE DELTA 30 OVERBANK	ELUTRIATE	92-C489	2.5	0.7	4.5	2.93	0.015	0.695	1.6	0.17	6.03	0	1	1	42.75	0.187	42	0.536	2.75	10	55
LAKE OAHE 1232	WATER	92-C459	60.9	20.9	3.75	52.3	0.026	0.402	9.6	0	8.39	0	190	156	650	0.034	167	0.008	0.39	217	408
LAKE OAHE 1232	SEDIMENT	92-C468																			
LAKE OAHE 1232	ELUTRIATE	92-C469	61.3	22	6.5	55.5	1.92	0	9.6	2.34	7.74	0	202	165	668	0.03	161	0.009	3.62	229	415
MOREAU DELTA 5	WATER	92-C458	62.8	19.1	3.18	48.5	0.054	0.141	9.1	0.018	8.06	2	185	155	677	0	186	0.019	0.18	200	422
MOREAU DELTA 5	SEDIMENT	92-C466																			
MOREAU DELTA 5	ELUTRIATE	92-C467	70.1	20.8	7.37	52.9	1.87	0.003	9.8	1.1	8.02	0	197	161	674	0.049	169	0.035	1.91	218	427
GRAND RIVER DELTA 10	WATER	92-C460	92.9	16.7	4.3	43.8	0.032	0.339	8.8	0.101	8.27	0	211	173	747	0.032	199	0.011	0.45	178	469
GRAND RIVER DELTA 10	SEDIMENT	92-C470																			
GRAND RIVER DELTA 10	ELUTRIATE	92-C471	98.2	17.7	6.9	42.6	1.94	0.006	8.9	2.39	7.69	0	260	213	741	0.04	159	0.001	3.24	179	461

Pesticides were also tested, but all tests were below detection limits thus no discussion of pesticides will be included in this report. In general, most parameters are not considered to be problematic except for arsenic which consistently shows large increases as a result of the elutriate process. It should be remembered that the stirring of bottom sediments in areas of the reservoir which are shallow is going to occur no matter what the pool elevation. This is a natural, on-going process which occurs at all reservoirs with relatively soft bed sediments.

Analysis of the data in Tables 4 and 5 indicate that most parameters are variable, sometimes increasing, decreasing or showing little or no change. This variation appears both within deltas and between deltas. Zinc, lead, iron and PH show consistent decreases upon elutriation indicating that for these metals a small improvement in water quality could result from wind-wave action. Consistent increases are seen in ammonia nitrogen and total kjeldahl nitrogen indicating that nutrient increases could be expected. Phosphorous levels however show a great deal of variation sometimes increasing, sometimes decreasing and sometimes showing no change.

Arsenic appears to be the parameter of greatest concern showing significant increases upon elutriation in most samples. The increase in arsenic sometimes exceeds a factor of 10 or more. In the delta areas which had four samples taken at different locations (Fort Peck, Little Missouri, and Lake Sakakawea), it is interesting to note that large increases in arsenic concentration upon elutriation are associated with finer sediments (Table 3).

In the case of Fort Peck, arsenic decreased upon elutriation when the percent sand increased from approximately one to over eight. This increase in coarseness was observed at the uppermost delta location. The change in percent sand, silt, and clay was expected <u>a priori</u> since it has been widely demonstrated that coarser materials will settle out upstream with finer sediments settling out further into the reservoir. In addition, finer sediments are generally more chemically active thus, perturbations such as wind-wave action can result in chemical changes associated with the transfer of materials from an anaerobic environment in the sediment to an aerobic environment in the overburden water. Table 3 shows similar patterns for the Little Missouri and Lake Sakakawea deltas although the increase in percent sand is more dramatic than that in Fort Peck. In addition, the Cheyenne River delta shows the same trend with increasing arsenic concentrations being inversely related to sediment particle size elutriated. The Oahe, Moreau, and Grand River deltas could not be analyzed for particle size relationship since only one sample was taken.

Past sampling has indicated that arsenic is a common water quality exceedence in Missouri River Basin Reservoirs which annually exceeds state ambient water quality standards. It is noted that a wide range on concentrations has been demonstrated to occur at a wide variety of sampling locations. It is suspected, although no specific studies have been accomplished, that high metals concentrations are associated with storm events which result in a large influx of water laden with sediment to the reservoir. In addition, high concentrations of metals could also result from strong winds, common to the Missouri River Basin, which result in littoral drift. Bank erosion is also a common problem at the mainstem reservoirs and would also result in high parameter levels if sampling happened to coincide with appropriate weather events.

It is important to understand that delta growth is a dynamic process and that as the reservoir fills, areas which are now comprised of fine sediments will eventually become areas dominated by more coarse sediments as the delta grows in the downstream direction. In addition, it is important to understand that the mainstem reservoirs were filled in stages with a particular pool elevation being maintained for a year or longer before filling was

TABLE 6

MEAN VALUES FOR COE AND USGS SURFACE WATER DATA

LOCATION	PERIOD OF RECORD	UG/L As	UG/L Ba	UG/L Cd	UG/L Cr	UG/L Cu	UG/L Fe	UG/L Pb	UG/L Mn	UG/L Zn	UG/L Se
MO RIVER AT ZORTMAN, MT (COE)	68-79	12.2	80.8	2.2	6.9	9.8	3014	26.3	53.6	30.9	0.625
MUSSELSHELL NR MOSBY, MT (COE)	68-79		69.5							12	2
BIG DRY NR VAN NORMAN, PECK (COE)	68-81	6.1	80.3	3.2	7.6	19.5	9179	23.9	179	23.2	0.666
FT PECK NR DAM (COE)	71-91	3.8	32.7	3	5.2	4.2	125	12.6	4	11.3	0.933
FT PECK AT HELL CK (COE)	76-90	4.8	32	2.3	1.4	5	206	14.6	10.8	10	1
FT PECK RELEASES (COE)	70-91	4.3	36.5	7.9	6	7.5	106	9.1	6.6	11.3	
MO R BELOW FT PECK (USGS)	75-87	3.8	160	0.8	10	8.1	185	6.6	16.8	26.2	1.1
MO R NR CULBERTSON , MT (USGS)	65-90	4.2	116	3.33	8.8	15.7	1919	6	63.1	45.3	1.1
MO R NR WILLISTON (USGS)	50-80	5.1	193	0.85	11.1	14	2827	11.8	133	63.8	1.3
LITTLE MO NR WATFORD CITY, ND (COE	71-76										
LITTLE MO NR WATFORD CITY, ND (USG	71-90	30.6	688	3.9	93.9	160	70981	104	2105	441	2.9
LAKE SAK AT NEWTOWN (COE)	71-90	2.9	51.8	1.6	5.3	7.2	359	18.1	16.3	20.4	0.79
LAKE SAK NR DAM (COE)	76-90	2.3	46.9	1.5	1.8	5	119	11	5.9	15.4	1
LAKE SAK RELEASES (COE)	70-76										
LAKE SAK RELEASES (USGS)	71-91	2	185	0.333	4.75	6	80.6	4.2	14.6	50.7	1
KNIFE RIVER AT HAZEN, ND (USGS)	50-90	2.3	186	2.4	12.6	14	1860	6.2	206	55.5	1
MO R NR SCHMIDT, ND (USGS)	74-81	2.6	100	0.285	8.6	8.2	1044	12.3	33.8	54.6	1.1
MO R AT BISMARCK (USGS)	69-89	2.1	66.6		3.3	8.1	976	10.2	33.3	32.7	1.5
HEART R NR LARK,ND (USGS)	71-83										
HEART R NR MANDAN (COE)	71-77						1406		132		
HEART R NR MANDAN (USGS)	78-83	2.31	163	0.83	10	11.1	4078	6.6	177	59	0.533
CANNONBALL NR BREIEN ND (COE)	71-76										
CANNONBALL NR BREIEN ND (USGS)	70-90	3.4	272	1.9	17.6	19.5	6450	9.7	250	104	
GRAND R NR LTTL EAGLE,SD (USGS)	68-90	3.4	160	2.4	20.8	24.3	7949	11.8	245	63.3	1.3
GRAND R NR LTTL EAGLE,SD (COE)	68-75		119				7570				
OAHE AT MOBRIDGE BRIDGE (COE)	72-76						330				
CHEYENNE R AT CHERRY CK, SD (USGS)	72-90	31.7	785	4.2	46	44.1	18605	43	664	124	4.2
CHEYENNE R NR EAGLE BUTTE, SD (COE	72-81		241								
MOREAU R NEAR WHITEHORSE, SD (COE)	71-81	6.6	100	3.7	67.8	63		70.7		231	3
MOREAU R NEAR WHITEHORSE, SD (USGS	72-90	5.5	456	1.1	30	38	23799	9.3	552	117	3.6
LAKE OAHE NR POLLOCK, SD (COE)	76-90	1.8	47.5	2	1.3	5.5	501	12.2	45.5	16.8	0.962
LAKE OAHE NR DAM (COE)	77-90	2	40	1.6	1.6	9.1	170	12.5	24.3	19.1	1.6
LAKE OAHE RELEASES (COE)	72-90	4	43	0.9	2.66	5	93.3	5	9.1	5.9	1

TABLE 7

MEAN VALUES FOR COE AND USGS SURFACE WATER DATA

LOCATION	PERIOD OF RECORD	UMHO CONDUC	pH	MG/L TOT ALK	HCO3	MG/L TDS	MG/L TKN	MG/L HARD	MG/L Ca	MG/L Mg	MG/L Na	MG/L K	MG/L CL-	MG/L SO4
MO RIVER AT ZORTHAN, MT (COE)	68-79	527	8.3	157	191	336	0.626	203	50.5	22.7	38.1	3.5	7.5	102
MUSSELSHELL NR MOSBY, MT (COE)	68-79	2040	8.2	239		1465	0.572	625	118	69	184	5.5	18.9	770
BIG DRY NR VAN NORMAN, PECK (COE)	68-81	2708	8.5	407	313	1731	0.93	212	48	98.5	484	7.3	11	837
FT PECK NR DAM (COE)	71-91	679	8.3	163	195	439	0.31	238	56.8	24.3	67.3	3.9	8	175
FT PECK AT HELL CK (COE)	76-90	639	8.3	160	192	433	0.318	234	56	24.2	64	3.8	8.8	165
FT PECK RELEASES (COE)	70-91	640	8.3	166		413	0.263	277	55.7	35.6	41.6	4.1	10.1	259
MO R BELOW FT PECK (USGS)	75-87	666	8.4	152	155		0.538	243	45.2	21.2	33		8.9	178
MO R NR CULBERTSON , MT (USGS)	65-90	670	8.1	158	187		0.641	229					8.7	169
MO R NR WILLISTON (USGS)	50-80	550	7.7	155	185	470	0.75	228					9.9	184
LITTLE MO NR WATFORD CITY, ND (COE	71-76	1331	8.1	348		1166	0.47	289	71.7	32.9			8.3	583
LITTLE MO NR WATFORD CITY, ND (USG	71-90		8.3	276	315		2.79	322					11.3	663
LAKE SAK AT NEWTOWN (COE)	71-90	670	8.2	149	191	419	0.403	205	51.4	19.9	54.8	3.6	8.5	170
LAKE SAK NR DAM (COE)	76-90	694	8.2	164	190	468	0.393	230	55.6	23.2	61.6	4.3	9.8	185
LAKE SAK RELEASES (COE)	70-76	627	8.3	154		446		220	65.7	29.9			8.7	171
LAKE SAK RELEASES (USGS)	71-91	680	8.1	169	198	430	0.444	219					9.8	139
KNIFE RIVER AT HAZEN, ND (USGS)	50-90	1440	8.1	427	410		1.18	310					5.8	413
MO R NR SCHMIDT, ND (USGS)	74-81	681	8.3	156	183		0.41	229					10.2	201
MO R AT BISMARCK (USGS)	69-89	673	8.3	154	190		0.344	228					10.2	191
HEART R NR LARK,ND (USGS)	71-83	1078	8.1	251	302			293					6.3	326
HEART R NR MANDAN (COE)	71-77	1347	8.5	303	332	920	0.678	302					6.9	370
HEART R NR MANDAN (USGS)	78-83	1319	8.2	321	305		1.01	313					12.8	415
CANNONBALL NR BREIEN ND (COE)	71-76	1946	8.4	329		1317	0.22	394	73	64.5			9.4	603
CANNONBALL NR BREIEN ND (USGS)	70-90	1753	8.3	367	420		1.4	453					14	662
GRAND R NR LTTL EAGLE,SD (USGS)	68-90	1852	8.3	350	380	155	1.3	261					26.4	624
GRAND R NR LTTL EAGLE,SD (COE)	68-75	1521	8.5	287		997	1.2	210	50	25.9			8	437
OAHE AT MOBRIDGE BRIDGE (COE)	72-76	671	8.5	157		445		213	52.8	20.7	54.3	16.6	7.8	171
CHEYENNE R AT CHERRY CK, SD (USGS)	72-90	2061	8.2	161	196	745	1.8	813	242	92	210	15.2	57.5	999
CHEYENNE R NR EAGLE BUTTE, SD (COE	72-81	1780	8	181		1584		695	193	73			36.2	816
MOREAU R NEAR WHITEHORSE, SD (COE)	71-81	1661	8.3	228		1167	3.1	259	39.8	15.5	111		10.7	597
MOREAU R NEAR WHITEHORSE, SD (USGS	72-90	1666	8.1	219	245	409	1.7	311					15.7	757
LAKE OAHE NR POLLOCK, SD (COE)	76-90	732	8.1	170	201	477	0.495	230	55.1	24	69.3	6.2	10.3	195
LAKE OAHE NR DAM (COE)	77-90	768	8.1	174	200	543	0.36	251	58.8	25.4	72.2	6.5	10.6	211
LAKE OAHE RELEASES (COE)	72-90	703	8.3	161		505	0.288	236	54.9	24	68.8	4.3	9.7	205

reinitiated. These brief periods of stability resulted in a series of small deltas forming at different areas within the reservoir. As a result, sampling sediment particle size at different points in the reservoir will yield both size and chemical differences, depending upon where the samples were taken. It should also be clearly understood that disruption of bottom sediments by wind-wave action, (essentially a natural elutriation process), is going to occur at all pool elevations.

CONCLUSIONS

Sediment samples taken in the delta areas of Fort Peck Lake, Lake Sakakawea, and Lake Oahe were tested using an elutriate process for a variety of parameters (Tables 4 and 5). Elutriate testing appeared to indicate that the parameter of major concern was arsenic which upon elutriation showed major increases where the percentage of sand was minimal (finer particle size)and generally showed decreases in arsenic concentrations when the percentage of sand increased/(coarser particle size). This finding is not surprising since silts and clays are more chemically active than sands. This finding would appear to indicate that water quality degradation associated with decreased pool elevations would increase since the wind-wave action associated with the shallow headwater areas of the lake would be disturbing finer sediments. It is important to note however, that the wind-wave action sediment disruption will occur no matter what the pool elevation and that it is usually not possible to maintain a constant elevation. It is also important to realize that delta formation is a dynamic process which will ultimately result in an increase in particle size with the areas of coarser and finer sediments forming further in the reservoir with the passage of time.

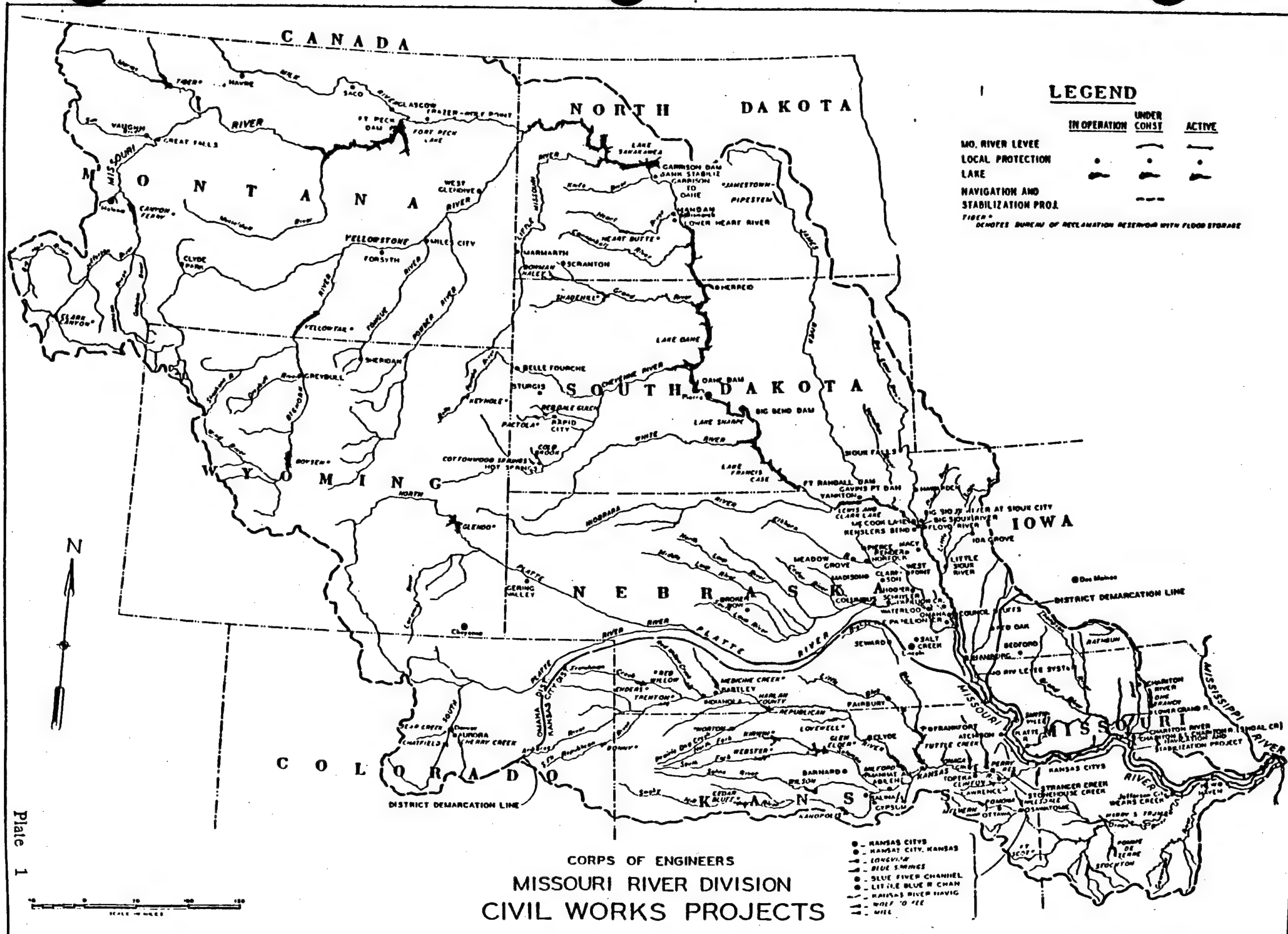

CORPS OF ENGINEERS
MISSOURI RIVER DIVISION
CIVIL WORKS PROJECTS
LEGEND
IN OPERATION
UNDER CONST
ACTIVE
MO. RIVER LEVEE
LOCAL PROTECTION
LAKE
NAVIGATION AND
STABILIZATION PROJ.
DENOTES BUREAU OF RECLAMATION RESERVOIR WITH FLOOD STORAGE
CANADA
MONTANA
NORTH DAKOTA
SOUTH DAKOTA
WYOMING
NEBRASKA
IOWA
COLORADO
KANSAS
MISSOURI
DISTRICT DEMARCATION LINE
N

Plate 1

SUMMARY OF ENGINEERING DATA — MISSOURI RIVER MAIN STEM RESERVOIRS

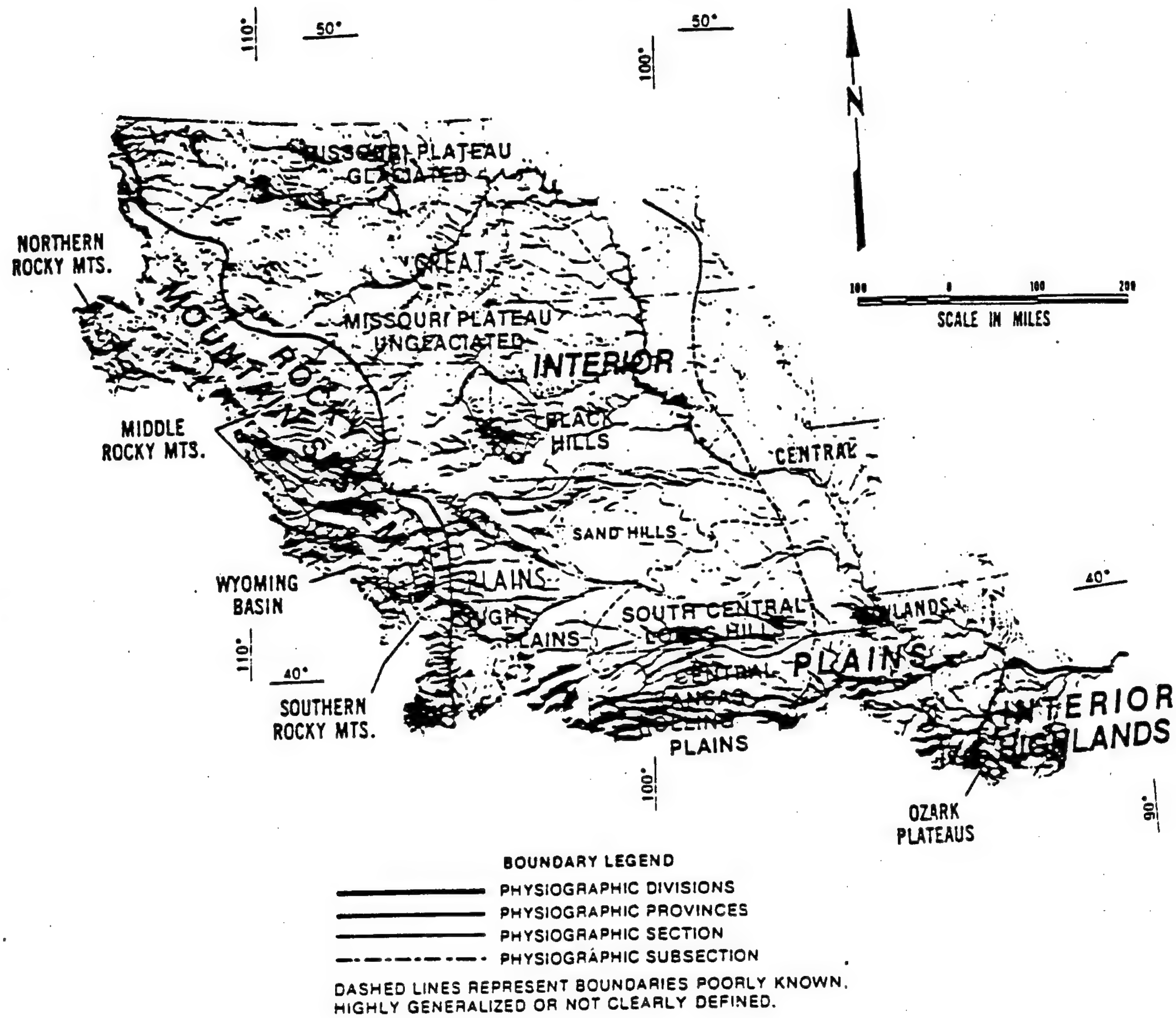
ITEM NO.	SUBJECT	FORT PECK LAKE	GARRISON DAM — LAKE SAKAKAWEA	OAHE DAM — LAKE OAHE	BIG BEND DAM — LAKE SHARPE	FORT RANDALL DAM — LAKE FRANCIS CASE	GAVINS POINT DAM — LEWIS & CLARK LAKE	TOTAL	ITEM NO.
1	Location of Dam	Near Glasgow, Montana	Near Garrison, N. Dak.	Near Pierre, S. Dak.	21 mi. upstream Chamberlain, S.D.	Near Lake Andes, S. Dak.	Near Yankton, S. Dak.		1
2	River Mile — 1960 mileage	Mile 1771.5	Mile 1389.9	Mile 1072.3	Mile 987.4	Mile 880.0	Mile 811.1		2
3	Total & Incremental Drainage Areas, square miles	57,500	181,400 (2) 123,900	243,490 (1) 62,090	249,330 (1) 5,840	263,480 (1) 14,150	279,480 (1) 16,000		3
4	Approximate length of full Reservoir (*in Valley Miles*)	134, ending near Zortman, Mont	178, ending near Trenton, N.D.	231, ending near Bismarck, N.D.	80, ending near Pierre, S.D.	107, ending at Big Bend Dam	25, ending near Niobrara, Nebr.	755 Miles	4
5	Shoreline — Miles (3)	1520 (*El. 2234*)	1340 (*El. 1837.5*)	2250 (*El. 1607.5*)	200 (*EL. 1420*)	540 (*El. 1350*)	90 (*El. 1204.5*)	5,940 miles	5
6	Average total & incremental inflow in cfs	10,200	25,600 15,400	28,900 3,300	28,900	30,000 1,100	32,000 2,000		6
7	Max. Discharge of Record near Damsite in cfs	137,000 (*June 1953*)	348,000 (*April 1952*)	440,000 (*April 1952*)	440,000 (*April 1952*)	447,000 (*April 1952*)	480,000 (*April 1952*)		7
8	Construction started — Cal. yr.	1933	1946	1948	1959	1946	1952		8
9	In operation (4) Cal. yr.	1940	1955	1962	1964	1953	1955		9
	DAM AND EMBANKMENT								
10	Top of Dam, Elev. ft. msl	2280.5	1875	1660	1440	1395	1234		10
11	Length of Dam in feet	21,026 (*excluding spillway*)	11,300 (*including spillway*)	9,300 (*excluding spillway*)	10,570 (*including spillway*)	10,700 (*including spillway*)	8,700 (*including spillway*)	71,596 feet	11
12	Damming Height, feet (5)	220	180	200	78	140	45	863 feet	12
13	Maximum Height, feet (5)	250.5	210	245	95	165	74		13
14	Max. Base width, total & w/o Berms, feet	3500;2700	3400; 2050	3500,1500	1200,700	4300,1250	850;450		14
15	Abutment Formations (*Under Dam & Embankment*)	Bearpaw shale and Glacial Till	Fort Union Clay-Shale	Pierre shale	Pierre shale & Niobrara chalk	Niobrara Chalk	Niobrara chalk & Carlile shale		15
16	Type of fill	Hydraulic & rolled earth fill	Rolled earth fill	Rolled earth fill & shale berms	Rolled earth, shale, chalk fill	Rolled earth fill & chalk berms	Rolled earth & chalk fill		16
17	Fill quantity, cu. yds	125,628,000	66,500,000	55,000,000 & 37,000,000	17,000,000	28,000,000 & 22,000,000	7,000,000	358,128,000 cu. yds.	17
18	Volume of concrete (Cu. yds.)	1,200,000	1,500,000	1,045,000	540,000	961,000	308,000	5,554,000 cu. yds.	18
19	Date of closure	24 June 1937	15 April 1953	3 August 1958	24 July 1963	20 July 1952	31 July 1955		19
	SPILLWAY DATA								
20	Location	Right bank — remote	Left bank — Adjacent	Right bank — remote	Left bank — adjacent	Left bank — adjacent	Right bank — adjacent		20
21	Crest Elevation, msl	2225	1825	1596.5	1385	1346	1180		21
22	Width (*including piers*) in feet	820 gated	1336 gated	456 gated	376 gated	1003 gated	664 gated		22
23	No., Size and Type of Gates	16 — 40'x25' Vertical Lift Gates	28 40'x29' Tainter	8-50'x23.5' Tainter	8-40'x38' Tainter	21-40'x29' Tainter	14-40'x30' Tainter		23
24	Design Discharge Capacity, cfs	275,000 at elev 2253.3	827,000 at elev 1858.5	304,000 at elev 1644.4	390,000 at elev 1433.6	620,000 at elev. 1379.3	584,000 at elev. 1221.4		24
25	Discharge Capacity at Maximum Operating Pool, cfs	230,000	660,000	80,000	270,000	508,000	345,000		25
	RESERVOIR DATA (6)								
26	Max. Operating Pool Elev. & Area	2250 msl 246,000 acres	1854 msl 380,000 acres	1620 msl 373,000 acres	1423 msl 61,000 acres	1375 msl 102,000 acres	1210 msl 31,000 acres	1,195,000 acres	26
27	Max. Nor. Op. Pool Elev. & Area	2246 msl 240,000 acres	1850 msl 364,000 acres	1617 msl 359,000 acres	1422 msl 60,000 acres	1365 msl 95,000 acres	1208 msl 28,000 acres	1,147,000 acres	27
28	Base Flood Control Elev. & Area	2234 msl 212,000 acres	1837.5 msl 307,000 acres	1607.5 msl 312,000 acres	1420 msl 57,000 acres	1350 msl 77,000 acres	1204.5 msl 25,000 acres	990,000	28
29	Min. Oper. Pool Elev. & Area	2160 msl 90,000 acres	1775 msl 128,000 acres	1540 msl 117,000 acres	1415 msl 51,000 acres	1320 msl 40,000 acres	1204.5 msl 25,000 acres	452,000	29
	Stor. Allocation, Elev. & Cap.								
30	Exclusive Flood Control	2250-2246 975,000 a.f.	1854-1850 1,489,000 a.f.	1620-1617 1,098,000 a.f.	1423-1422 60,000 a.f.	1375-1365 986,000 a.f.	1210-1208 60,000 a.f.	4,668,000	30
31	Flood Control & Multiple Use	2246-2234 2,717,000 a.f.	1850-1837.5 4,222,000 a.f.	1617-1607.5 3,186,000 a.f.	1422-1420 117,000 a.f.	1365-1350 1,315,000 a.f.	1208-1204.5 92,000 a.f.	11,649,000	31
32	Carryover Multiple Use	2234-2160 10,785,000 a.f.	1837.5-1775 13,130,000 a.f.	1607.5-1540 13,603,000 a.f.		1350-1320 1,648,000 a.f.		39,166,000	32
33	Permanent	2160-2030 4,211,000 a.f.	1775-1673 4,980,000 a.f.	1540-1415 5,451,000 a.f.	1420-1345 1,682,000 a.f.	1320-1240 1,545,000 a.f.	1204.5-1160 340,000 a.f.	18,209,000	33
34	Gross	2250-2030 18,688,000 a.f.	1854-1673 23,821,000 a.f.	1620-1415 23,338,000 a.f.	1423-1345 1,859,000 a.f.	1375-1240 5,494,000 a.f.	1210-1160 492,000 a.f.	73,692,000	34
35	Reservoir filling initiated	November 1937	December 1953	August 1958	November 1963	January 1953	August 1955		35
36	Initially reached Min. Oper. Pool	27 May 1942	7 August 1955	3 April 1962	25 March 1964	24 November 1953	22 December 1955		36
37	Est. Annual Sediment Inflow	18,100 a.f. 1030 yrs	25,900 a.f. 920 yrs	23,000 a.f. 1010 yrs	4,300 a.f. 350 yrs	21,600 a.f. 250 yrs	2,600 a.f. 160 yrs	95,700 a.f.	37
	OUTLET WORKS DATA								
38	Location	Right bank	Right bank	Right bank		Left bank			38
39	Number and size of conduits	2- 24'8" dia (No's 3 & 4)	1 26' dia and 2-22' dia.	6 19.75' dia upstream, 18.25' dia downstream	None (7)	4 22' diameter	None (7)		39
40	Length of Conduits in feet (8)	No. 3—6,615, No. 4—7,240	1529	3496 to 3659		1013			40
41	No., Size and Type of Service Gates	1—28' dia. cylindrical gate 6 ports 7.6'x8.5' high (*net opening*) in each control shaft	1-18'x24.5' Tainter gate per conduit for fine regulation	1 13'x22' per conduit, vertical lift; 4 cable suspension and 2 hydraulic suspension (*fine regulation*)		2 11'x23' per conduit, vertical lift, cable suspension.			41
42	Entrance Invert Elevation	2095	1672	1425	1385 (12)	1229	1180 (12)		42
43	Avg. Discharge Cap. per conduit & total	Elev. 2250 22,500 cfs—45,000 cfs	Elev. 1854 30,400 cfs-98,000 cfs	Elev. 1620 18,500 cfs-111,000 cfs		Elev. 1375 32,000 cfs-128,000 cfs			43
44	Present Tailwater Elev. (msl)	2032—2036 5,000—35,000 cfs	1672-1680 15,000-60,000 cfs	1423-1428 25,000-55,000 cfs	1351-1355 (11) 25,000-100,000 cfs	1230-1239 5,000-60,000 cfs	1158-1165 15,000-60,000 cfs		44
	POWER FACILITIES AND DATA								
45	Avg. Gross Head avail. in ft. (13)	194	161	174	70	117	48	764 feet	45
46	Number and size of conduits	No. 1-24'8" dia; No. 2-22'4" dia	5 29' dia., 25' penstocks	7-24' dia., imbedded penstocks	None; direct intake	8 28' dia., 22' penstocks	None; direct intake		46
47	Length of conduits in feet (8)	No. 1-5,653; No. 2-6,355	1,829	From 3,280 to 4,005		1,074			47
48	Surge Tanks	PH#1: 3-40' dia; PH#2 2-65' dia	65' dia., 2 per penstock	70' dia., 2 per penstock	None	59' dia., 2 per alternate penstock	None	55,083 feet	48
49	No., type and speed of turbines	5-Francis, PH#1-2-128.5, 1-164 rpm PH#2-2-128.6 rpm	5 Francis, 90 rpm	7 Francis, 100 rpm	8 Fixed blade, 81.8 rpm	8 Francis, 85.7 rpm	3 Kaplan, 75 rpm	36 Units	49
50	Disch. Cap. at Rated Head-cfs	PH#1 units 1 & 3 170', 2-140' 8,800 cfs, PH#2-2-170-7,200 cfs	150' 38,000 cfs	185' 54,000 cfs	67' 103,000 cfs	112' 44,500 cfs	48' 36,000 cfs		50
51	Gen. Nameplate Rating, kw	2-43,500; 1-18,250; 2-40,000	3-109,250; 2-95,000	112,290	58,500	40,000	44,100		51
52	Plant capacity, kw	185,250	517,750	786,030	468,000	320,000	132,300	2,409,330 kw	52
53	Dependable capacity, kw (9)	181,000	388,000	534,000	497,000	293,000	74,000	1,987,000	53
54	Average Annual Energy Million kwh (13)	1,044	2,354	2,694	1,001	1,745	700	9,538	54
55	Initial Gen., First & Last Unit	July 1943 — June 1961	January 1956 — October 1960	April 1962 — June 1963	October 1964 — July 1966	March 1954 — January 1956	September 1956 — January 1957	July 1943 — July 1966	55
56	Estimated cost September 1989 Completed project (14)	$158,428,000	$299,938,000	$346,521,000	$107,498,000	$199,068,000	$49,617,000	1,161,068,000	56

REMARKS

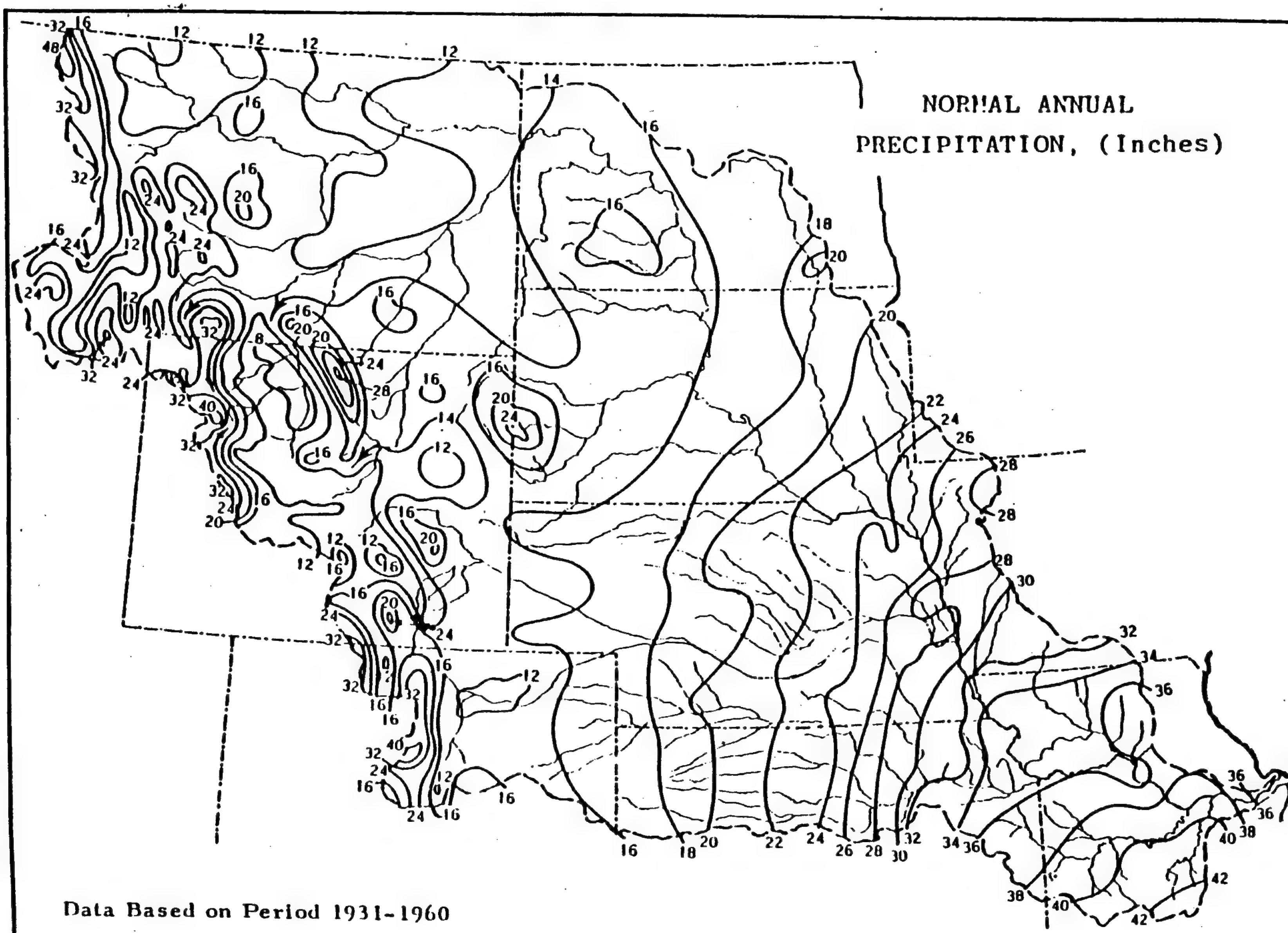
(1) Includes 4,280 square miles of non-contributing areas.
(2) Includes 1,350 square miles of non-contributing areas.
(3) With pool at base of flood control.
(4) Storage first available for regulation of flows.
(5) Damming height is height from low water to maximum operating pool. Maximum height is from average streambed to top of dam.
(6) Based on latest available storage data.
(7) River regulation is attained by flows over low crested spillway and through turbine.
(8) Length from upstream face of outlet or to spiral case.
(9) Based on 8th year (1961) of drought drawdown. (From study 8-83-1985).
(10) Storage volumes are exclusive of Snake Creek arm.
(11) Affected by level of Lake Francis Case. Applicable to pool at elevation 1350.
(12) Spillway Crest.
(13) Based on study 8-83 1985.
(14) Source: Annual Report on Civil Works Activities of the Corps of Engineers. Extract Report Fiscal Year 1991

Corps of Engineers, U.S. Army
Compiled by
Missouri River Division
October 1992

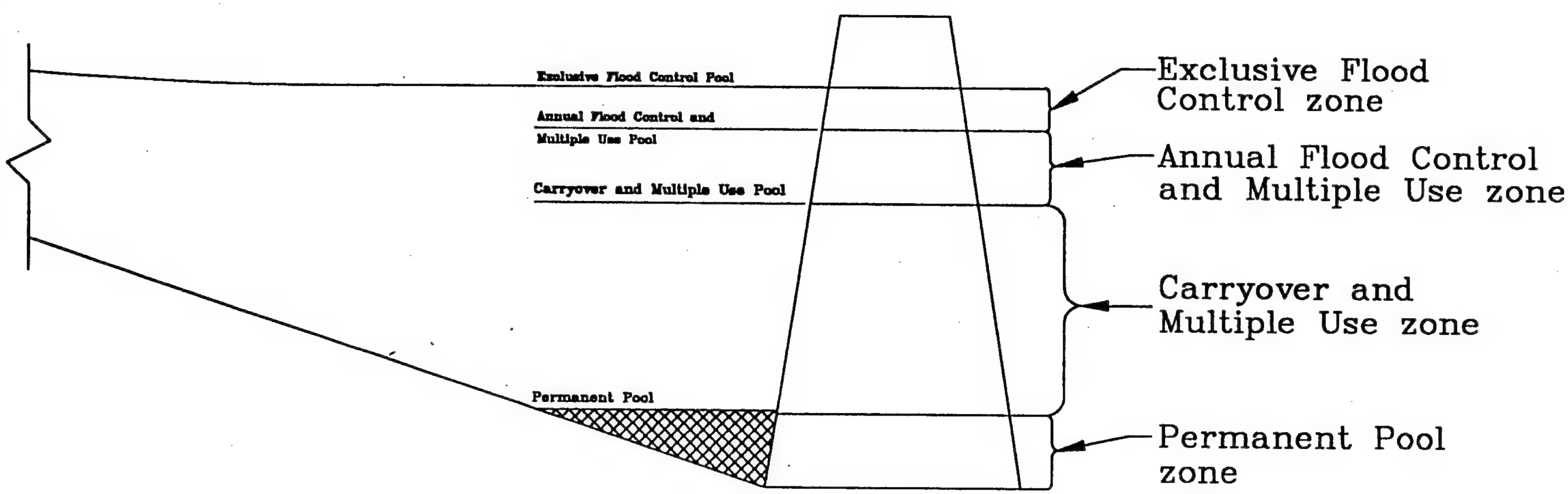
PHYSIOGRAPHIC FEATURES OF THE MISSOURI BASIN



NORMAL ANNUAL PRECIPITATION, (Inches)

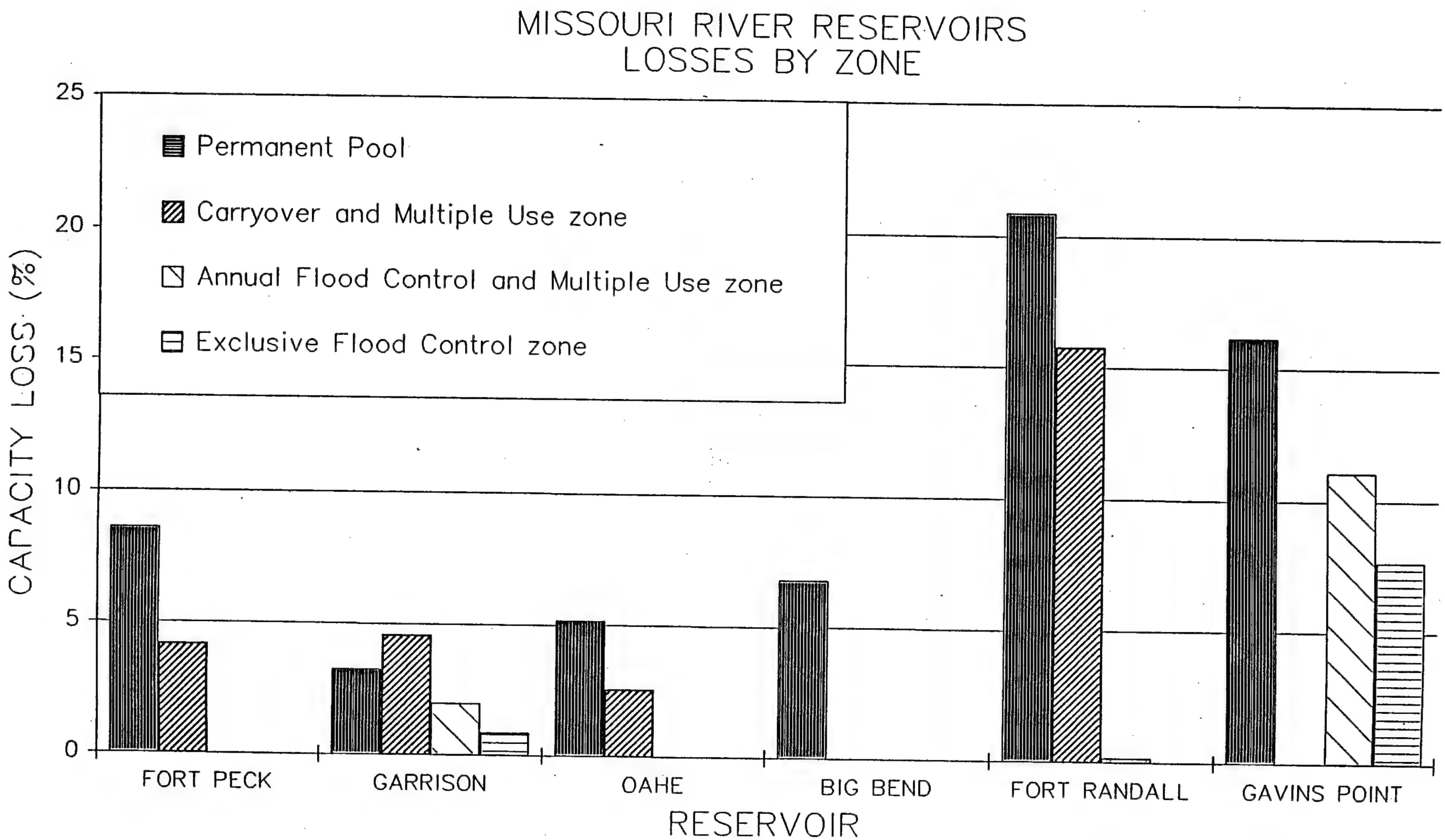


Data Based on Period 1931-1960



NO SCALE

Illustration showing reservoir zone locations.



MISSOURI RIVER RESERVOIRS
LOSSES BY ZONE
CAPACITY LOSS (%)
25
20
15
10
5
0
Permanent Pool
Carryover and Multiple Use zone
Annual Flood Control and Multiple Use zone
Exclusive Flood Control zone
FORT PECK
GARRISON
OAHE
BIG BEND
FORT RANDALL
GAVINS POINT
RESERVOIR

OMAHA DISTRICT MISSOURI RIVER MAINSTEM LAKES
SUMMARY OF RESERVOIR SURVEYS AND ASSOCIATED STORAGE LOSS BY ZONE

SUMMARY OF RESERVOIR SURVEYS AND STORAGE CHANGES -- MISSOURI RIVER MAIN STEM

RESERVOIR	YEAR	TOTAL STORAGE BELOW THE POOL ELEV IN 1,000 ACRE FEET				INCREMENTAL STORAGE IN 1000 ACRE FEET				INCREMENTAL STORAGE CHANGE SINCE THE ORIGINAL IN 1,000 AC-FT				INCREMENTAL STORAGE CHANGE SINCE THE ORIGINAL IN PERCENTAGE						
		EXCLUSIVE FLOOD CONTROL	FLOOD CONTROL & MULTIPLE USE	CARRYOVER MULTIPLE USE	PERMANENT POOL	EXCLUSIVE FLOOD CONTROL	FLOOD CONTROL & MULTIPLE USE	CARRYOVER MULTIPLE USE	PERMANENT POOL	EXCLUSIVE FLOOD CONTROL	FLOOD CONTROL & MULTIPLE USE	CARRYOVER MULTIPLE USE	PERMANENT POOL	EXCLUSIVE FLOOD CONTROL	FLOOD CONTROL & MULTIPLE USE	CARRYOVER MULTIPLE USE	PERMANENT POOL	TOTAL STORAGE LOSS 1000 AC-FT	TOTAL STORAGE LOSS %	ANNUAL LOSS %
FORT PECK																				
POOL ELEVATION		2,250	2,246	2,234	2,160	2,250	2,246	2,234	2,160	2,250	2,246	2,234	2,160	2,250	2,246	2,234	2,160			
ORIGINAL	1938	19,557	18,587	15,869	4,607	970	2,718	11,262	4,607											
	1950	19,234	18,263	15,545	4,378	971	2,718	11,167	4,378	-1	0	95	229	-0.1	0.0	0.8	5.0	323	1.7	0.14
	1952	19,187	18,216	15,498	4,378	971	2,718	11,120	4,378	-1	0	142	229	-0.1	0.0	1.3	5.0	370	1.9	0.14
	1954	19,164	18,194	15,476	4,378	970	2,718	11,098	4,378	0	0	164	229	0.0	0.0	1.5	5.0	393	2.0	0.13
	1958	19,162	18,192	15,470	4,349	970	2,722	11,121	4,349	0	-4	141	258	0.0	-0.1	1.3	5.6	395	2.0	0.10
	1961	19,138	18,167	15,445	4,346	971	2,722	11,099	4,346	-1	-4	163	261	-0.1	-0.1	1.4	5.7	419	2.1	0.09
	1972	18,909	17,932	15,228	4,283	977	2,704	10,945	4,283	-7	14	317	324	-0.7	0.5	2.8	7.0	648	3.3	0.10
	1987	18,688	17,713	14,996	4,211	975	2,717	10,785	4,211	-5	1	477	396	-0.5	0.0	4.2	8.6	869	4.4	0.09
GARRISON																				
POOL ELEVATION		1,854	1,850	1,837.5	1,775	1,854	1,850	1,937.5	1,775	1,854	1,850	1,937.5	1,775	1,854	1,850	1,937.5	1,775			
ORIGINAL	1953	24,728	23,225	18,917	5,152	1,503	4,308	13,765	5,152											
	1958	24,504	23,000	18,694	5,004	1,504	4,306	13,690	5,004	-1	2	75	148	-0.1	0.0	0.5	2.9	224	0.9	0.18
	1959	24,477	22,973	18,670	4,989	1,504	4,303	13,681	4,989	-1	5	84	163	-0.1	0.1	0.6	3.2	251	1.0	0.17
	1964	24,355	22,846	18,517	4,981	1,509	4,329	13,536	4,981	-6	-21	229	171	-0.4	-0.5	1.7	3.3	373	1.5	0.14
	1969	24,137	22,635	18,348	4,976	1,502	4,287	13,372	4,976	1	21	393	176	0.1	0.5	2.9	3.4	591	2.4	0.15
	1979	23,923	22,439	18,209	4,990	1,494	4,220	13,219	4,990	9	88	546	162	0.6	2.0	4.0	3.1	805	3.3	0.13
	1988	23,821	22,332	18,110	4,980	1,489	4,222	13,130	4,980	14	86	635	172	0.9	2.0	4.6	3.3	907	3.7	0.11
OAHE																				
POOL ELEVATION		1,620	1,617	1,607.5	1,540	1,620	1,617	1,607.5	1,540	1,620	1,617	1,607.5	1,540	1,620	1,617	1,607.5	1,540			
ORIGINAL	1958	23,751	22,649	19,490	5,665	1,102	3,159	13,825	5,665											
	1963	23,647	22,545	19,386	5,575	1,102	3,159	13,811	5,575	0	0	14	90	0.0	0.0	0.1	1.6	104	0.4	0.09
	1968	23,507	22,416	19,239	5,521	1,091	3,177	13,718	5,521	11	-18	107	144	1.0	-0.6	0.8	2.5	244	1.0	0.10
	1976	23,337	22,240	19,054	5,451	1,097	3,186	13,603	5,451	5	-27	222	214	0.5	-0.9	1.6	3.8	414	1.7	0.10
	1989	23,137	22,035	18,834	5,373	1,102	3,201	13,461	5,373	0	-42	364	292	0.0	-1.3	2.6	5.2	614	2.6	0.08
(1) BIG BEND																				
POOL ELEVATION		1,423	1,422		1,420	1,423	1,422		1,420	1,423	1,422		1,420	1,423	1,422		1,420			
ORIGINAL	1956	1,999	1,939		1,823	60	116		1,823											
	1963	1,980	1,920		1,804	60	116		1,804	0	0		19	0.0	0.0		1.0	19	1.0	0.14
	1971	1,915	1,855		1,738	60	117		1,738	0	-1		85	0.0	-0.9		4.7	84	4.2	0.28
	1975	1,908	1,847		1,730	61	117		1,730	-1	-1		93	-1.7	-0.9		5.1	91	4.6	0.24
	1979	1,884	1,821		1,699	63	122		1,699	-3	-6		124	-5.0	-5.2		6.8	115	5.8	0.25
	1983	1,874	1,814		1,697	60	117		1,697	0	-1		126	0.0	-0.9		5.9	125	6.3	0.23
	1991	1,859	1,799		1,682	60	117		1,682	0	-1		141	0.0	-0.9		7.7	140	7.0	0.20

(1) INCLUDES VOLUME LOSS UPSTREAM OF BIG BEND DUE TO SEDIMENT INFLOW INTO FORT RANDALL FROM 1952 TO 1963

OMAHA DISTRICT MISSOURI RIVER MAINSTEM LAKES

SUMMARY OF RESERVOIR SURVEYS AND ASSOCIATED STORAGE LOSS BY ZONE

RESERVOIR	YEAR	TOTAL STORAGE BELOW THE POOL ELEV IN 1,000 ACRE FEET				INCREMENTAL STORAGE IN 1000 ACRE FEET				INCREMENTAL STORAGE CHANGE SINCE THE ORIGINAL IN 1,000 AC-FT				INCREMENTAL STORAGE CHANGE SINCE THE ORIGINAL IN PERCENTAGE						
		EXCLUSIVE FLOOD CONTROL	FLOOD CONTROL & MULTIPLE USE	CARRYOVER MULTIPLE USE	PERMANENT POOL	EXCLUSIVE FLOOD CONTROL	FLOOD CONTROL & MULTIPLE USE	CARRYOVER MULTIPLE USE	PERMANENT POOL	EXCLUSIVE FLOOD CONTROL	FLOOD CONTROL & MULTIPLE USE	CARRYOVER MULTIPLE USE	PERMANENT POOL	EXCLUSIVE FLOOD CONTROL	FLOOD CONTROL & MULTIPLE USE	CARRYOVER MULTIPLE USE	PERMANENT POOL	TOTAL STORAGE LOSS 1000 AC/FT	TOTAL STORAGE LOSS %	ANNUAL LOSS %
(2) BIG BEND																				
POOL ELEVATION		1,423	1,422		1,420	1,423	1,422		1,420	1,423	1,422		1,420	1,423	1,422		1,420			
ORIGINAL	1963	1,980	1,920		1,804	60	116		1,804											
	1971	1,915	1,855		1,738	60	117		1,738	0	-1		66	0.0	-0.9		3.7	65	3.3	0.41
	1975	1,908	1,847		1,730	61	117		1,730	-1	-1		74	-1.7	-0.9		4.1	72	3.6	0.30
	1979	1,884	1,821		1,699	63	122		1,699	-3	-6		105	-5.0	-5.2		5.8	96	4.8	0.30
	1983	1,874	1,814		1,697	60	117		1,697	0	-1		107	0.0	-0.9		5.9	106	5.4	0.27
	1991	1,859	1,799		1,682	60	117		1,682	0	-1		122	0.0	-0.9		6.8	121	6.1	0.22
	(2) VOLUME LOSS AFTER CLOSURE OF BIG BEND																			
FORT RANDALL																				
POOL ELEVATION		1,375	1,365	1,350	1,320	1,375	1,365	1,350	1,320	1,375	1,365	1,350	1,320	1,375	1,365	1,350	1,320			
ORIGINAL	1953	6,208	5,229	3,911	1,953	979	1,318	1,958	1,953											
	1957	5,917	4,937	3,616	1,739	980	1,321	1,877	1,739	-1	-3	81	214	-0.1	-0.2	4.1	11.0	291	4.7	1.17
	1962	5,816	4,834	3,529	1,761	982	1,305	1,768	1,761	-3	13	190	192	-0.3	1.0	9.7	9.8	392	6.3	0.70
	1967	5,750	4,767	3,447	1,640	983	1,320	1,807	1,640	-4	-2	151	313	-0.4	-0.2	7.7	16.0	458	7.4	0.53
	1073	5,634	4,650	3,334	1,573	984	1,316	1,761	1,573	-5	2	197	380	-0.5	0.2	10.1	19.5	574	9.2	-0.01
	1977	5,603	4,619	3,301	1,570	984	1,318	1,731	1,570	-5	0	227	383	-0.5	0.0	11.6	19.6	605	9.7	0.41
	1981	5,574	4,589	3,267	1,568	985	1,322	1,699	1,568	-6	-4	259	385	-0.6	-0.3	13.2	19.7	634	10.2	0.36
	1986	5,494	4,508	3,193	1,545	986	1,315	1,648	1,545	-7	3	310	408	-0.7	0.2	15.8	20.9	714	11.5	0.35
GAVINS POINT																				
POOL ELEVATION		1,210	1,208		1,205	1,210	1,208		1,205	1,210	1,208		1,205	1,210	1,208		1,205			
ORIGINAL	1955	575	510		420	65	90		420											
	1960	560	496		408	64	88		408	1	2		12	1.5	2.2		2.9	15	2.6	0.52
	1965	536	473		374	63	99		374	2	-9		46	3.1	-10.0		11.0	39	6.8	0.68
	1970	522	460		362	62	98		362	3	-8		58	4.6	-8.9		13.8	53	9.2	0.61
	1975	517	455		358	62	97		358	3	-7		62	4.6	-7.8		14.8	58	10.1	0.50
	1979	504	443		360	61	83		360	4	7		60	6.2	7.8		14.3	71	12.3	0.51
	1985	492	432		352	60	80		352	5	10		68	7.7	11.1		16.2	83	14.4	0.48

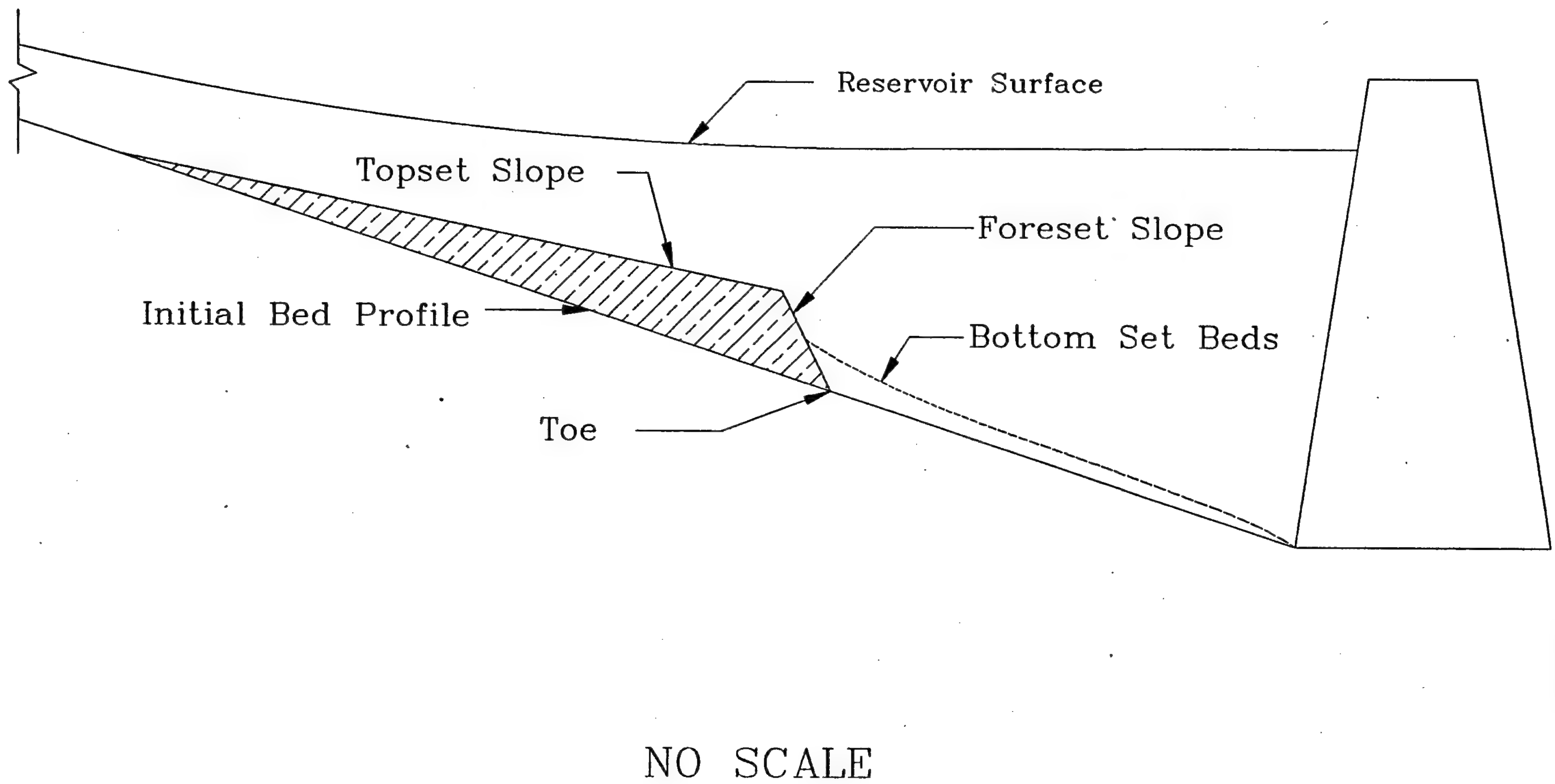
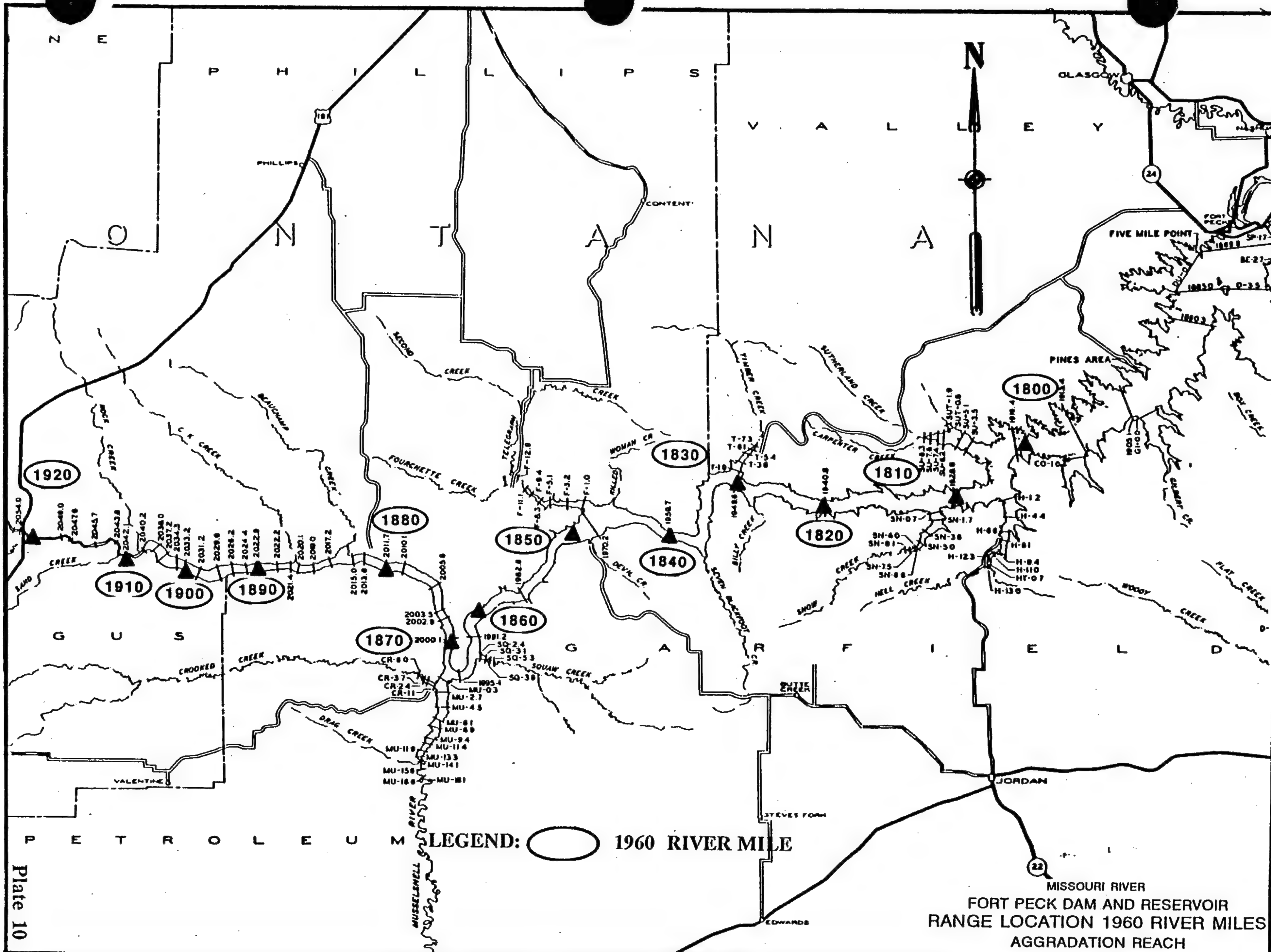
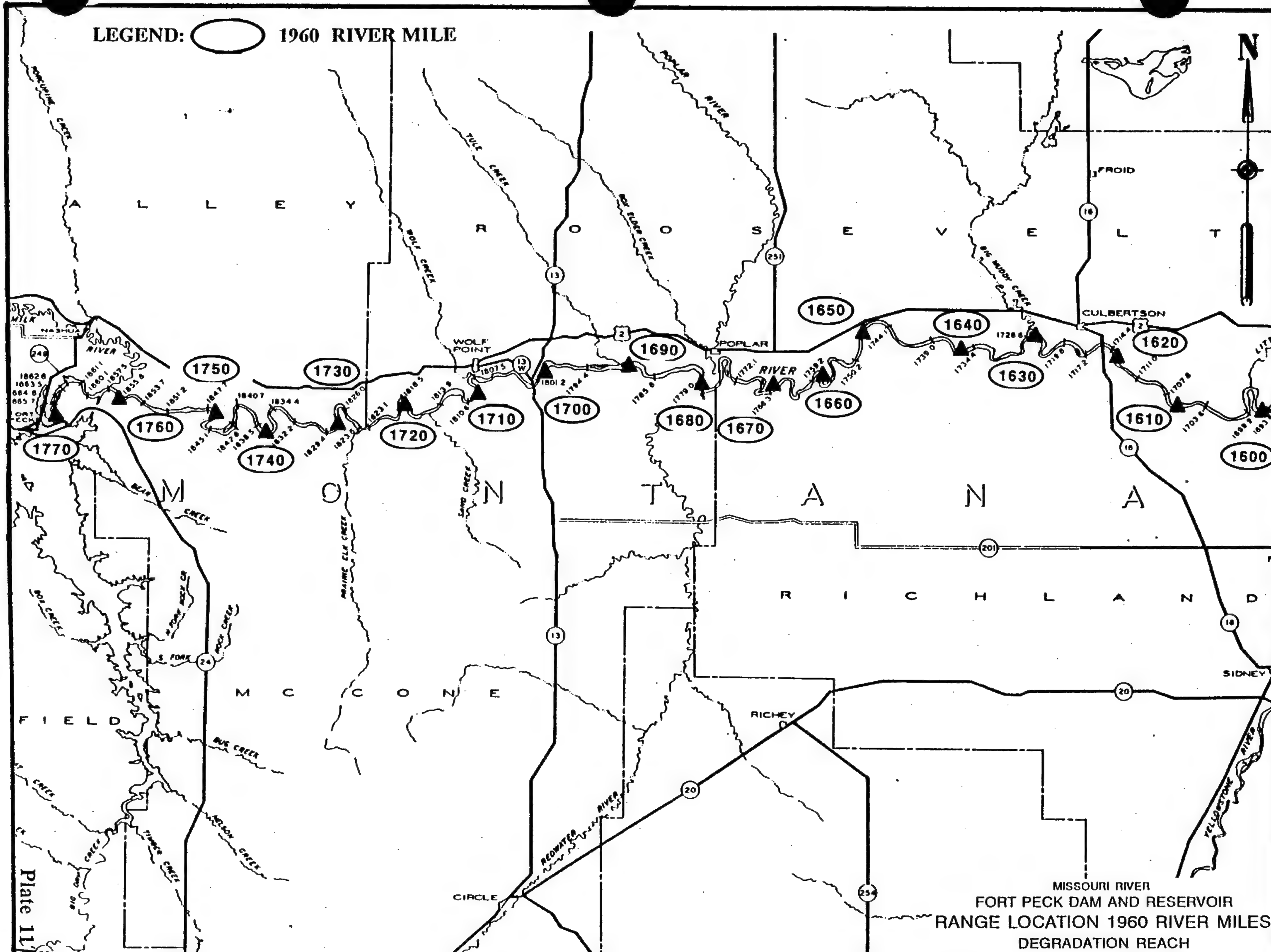


Illustration showing the idealized delta formation.



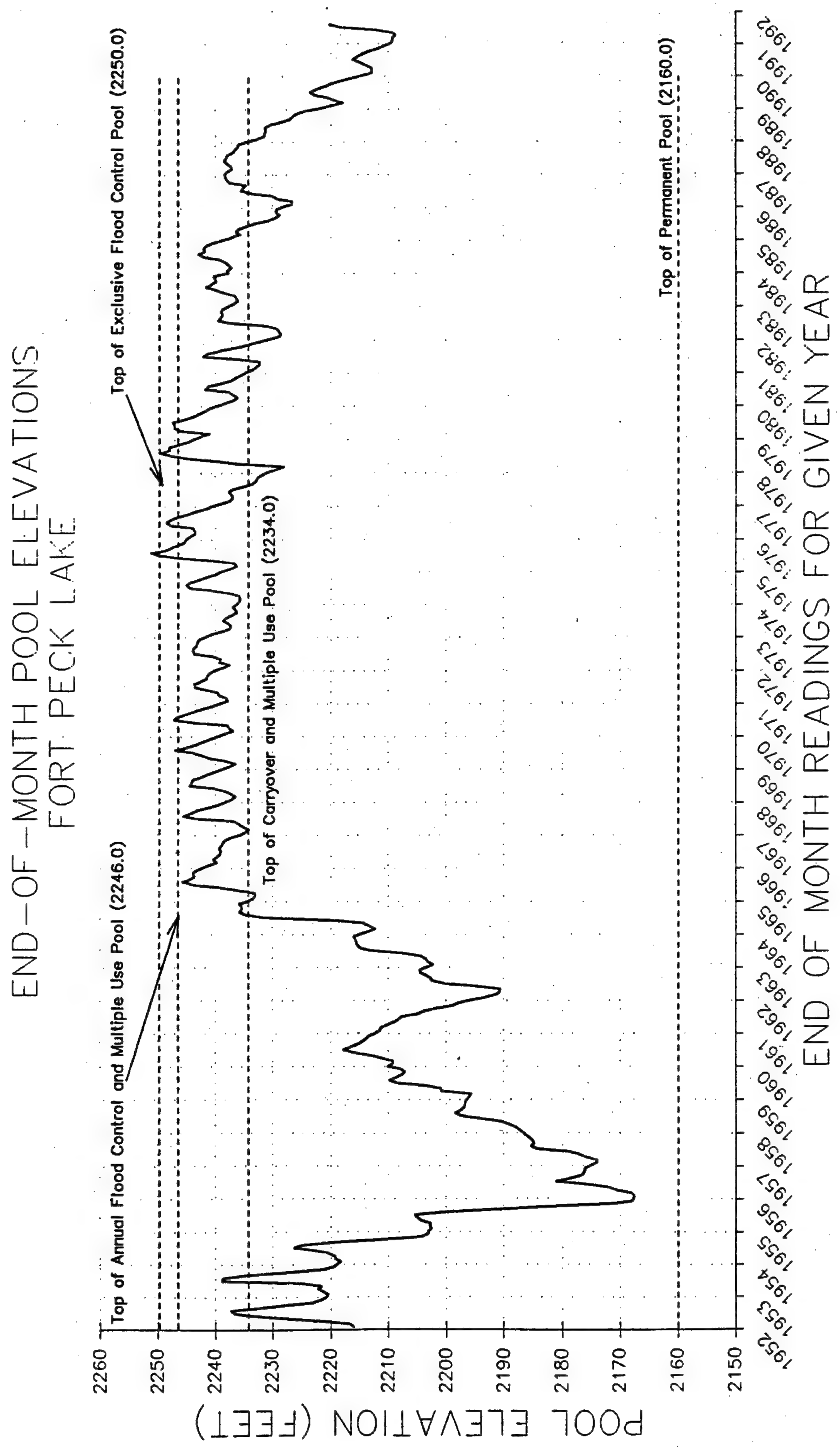
PHILLIPS
VALLEY
MONTANA
GARFIELD
PETROLEUM
GLASGOW
FIVE MILE POINT
PINES AREA
JORDAN
PHILLIPS
CONTENT
VALENTINE
EDWARDS
1800
1810
1820
1830
1840
1850
1860
1870
1880
1890
1900
1910
1920
LEGEND: 1960 RIVER MILE
MISSOURI RIVER
FORT PECK DAM AND RESERVOIR
RANGE LOCATION 1960 RIVER MILES
AGGRADATION REACH

Plate 10



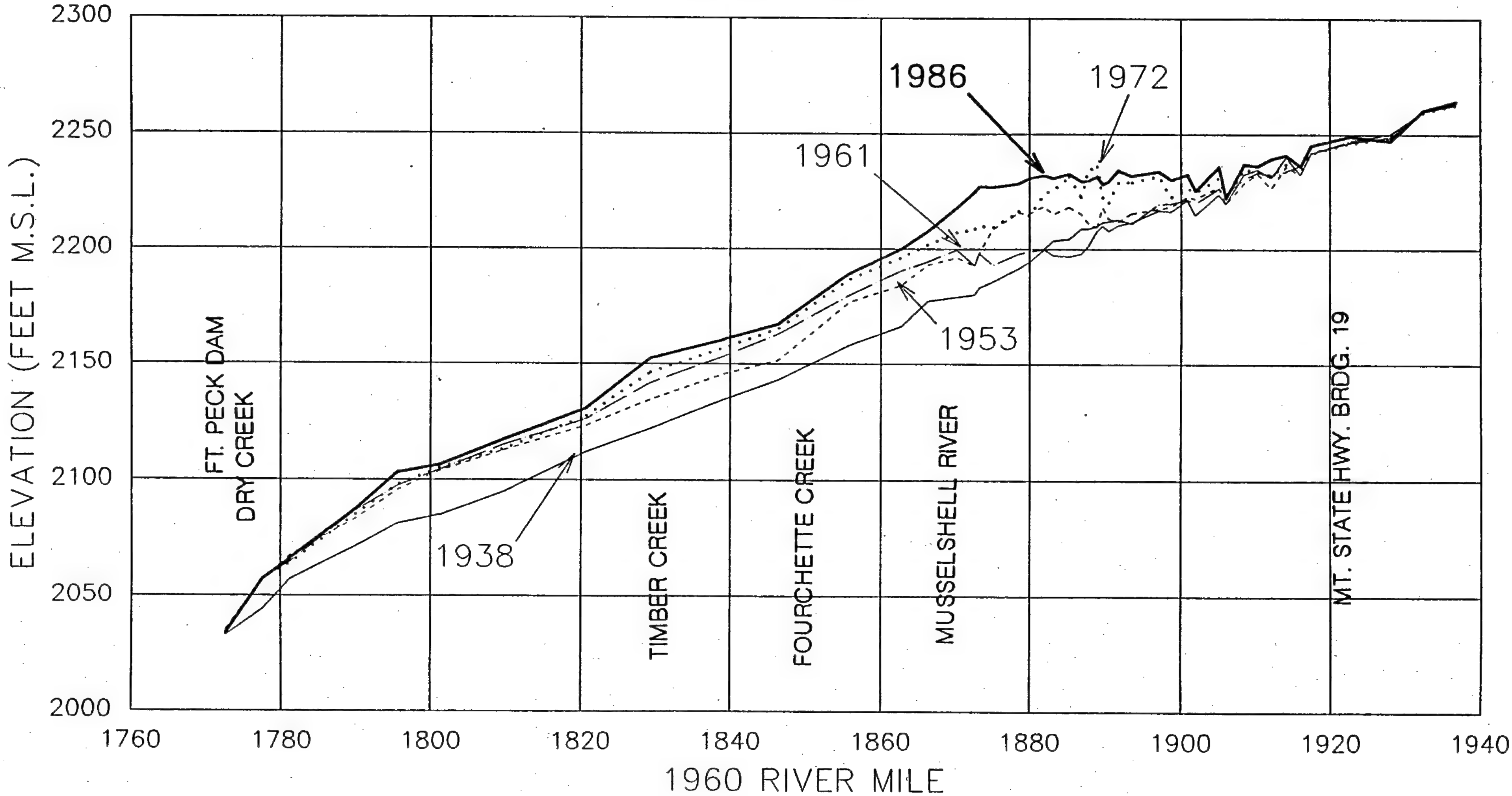
MISSOURI RIVER
FORT PECK DAM AND RESERVOIR
RANGE LOCATION 1960 RIVER MILES
DEGRADATION REACH

Plate 11



END-OF-MONTH POOL ELEVATIONS
FORT PECK LAKE
Top of Exclusive Flood Control Pool (2250.0)
Top of Annual Flood Control and Multiple Use Pool (2246.0)
Top of Carryover and Multiple Use Pool (2234.0)
Top of Permanent Pool (2160.0)
POOL ELEVATION (FEET)
2260
2250
2240
2230
2220
2210
2200
2190
2180
2170
2160
2150
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
END OF MONTH READINGS FOR GIVEN YEAR

FORT PECK AGGRADATION REACH
THALWEG PROFILE



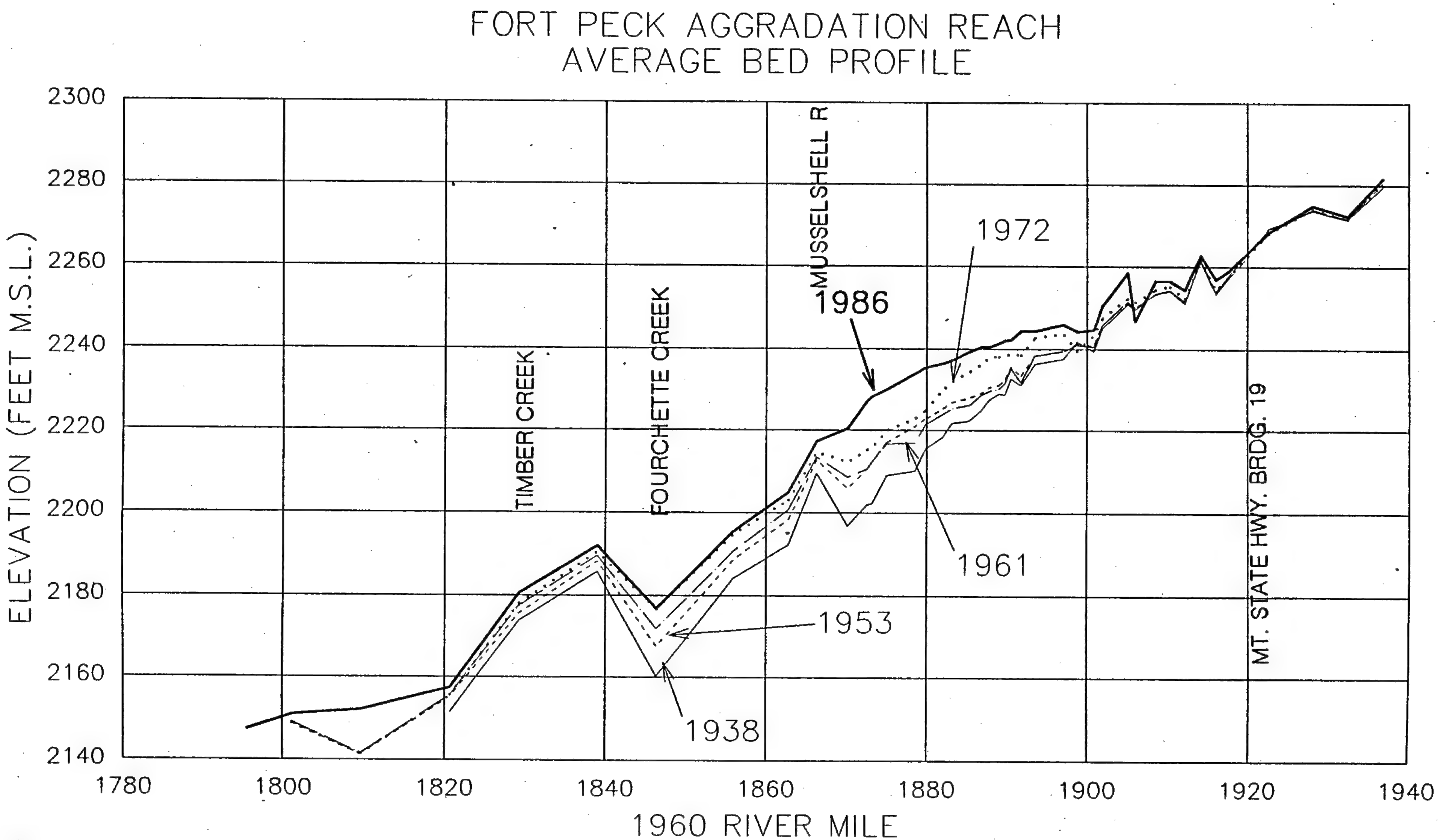
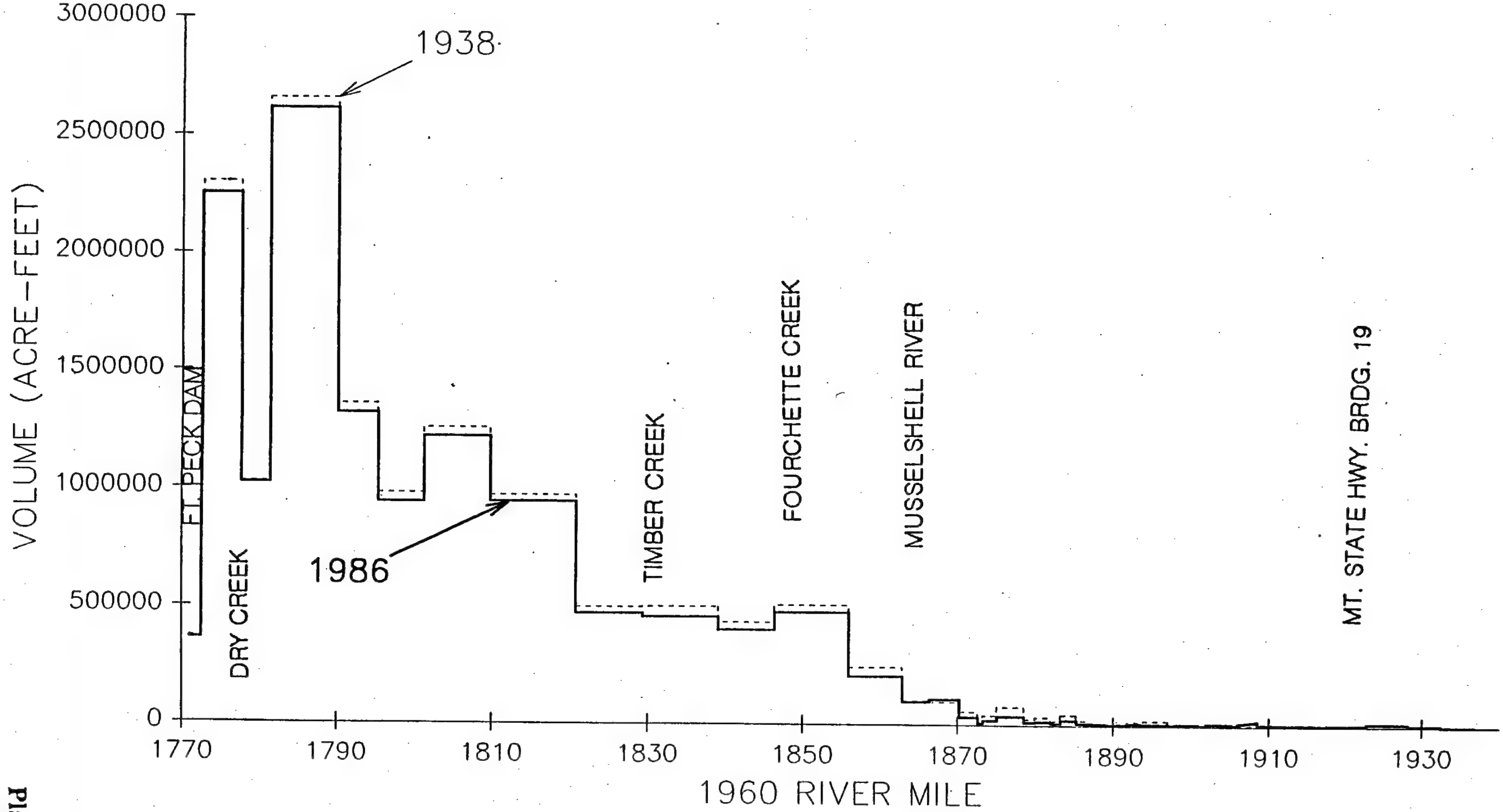

FORT PECK AGGRADATION REACH
AVERAGE BED PROFILE
ELEVATION (FEET M.S.L.)
2300
2280
2260
2240
2220
2200
2180
2160
2140
1780
1800
1820
1840
1860
1880
1900
1920
1940
1960 RIVER MILE
TIMBER CREEK
FOURCHETTE CREEK
MUSSELSHELL R
MT. STATE HWY. BRDG. 19
1986
1972
1961
1953
1938

Plate 14

FORT PECK AGGRADATION REACH
VOLUME BY SEGMENT



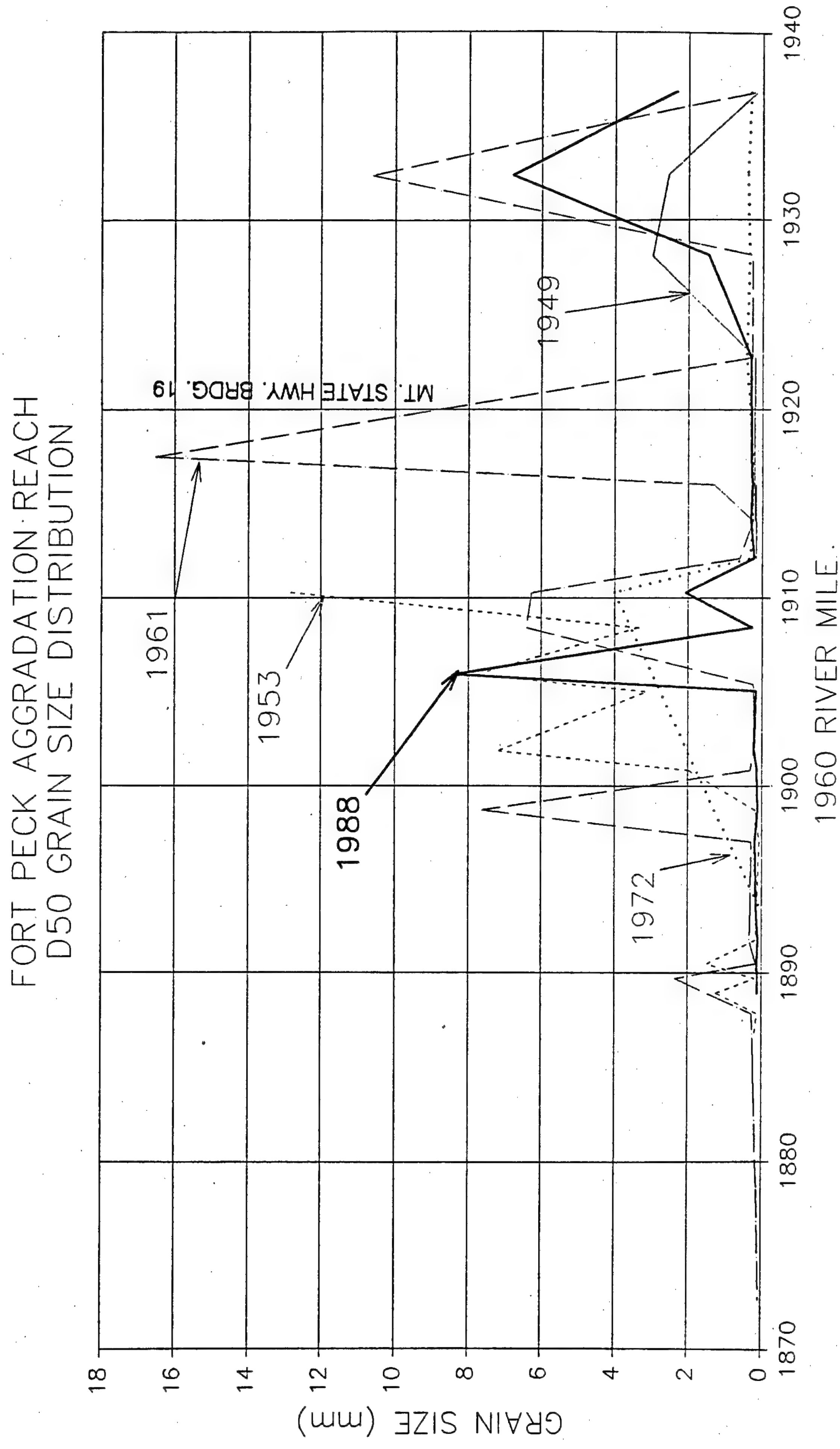
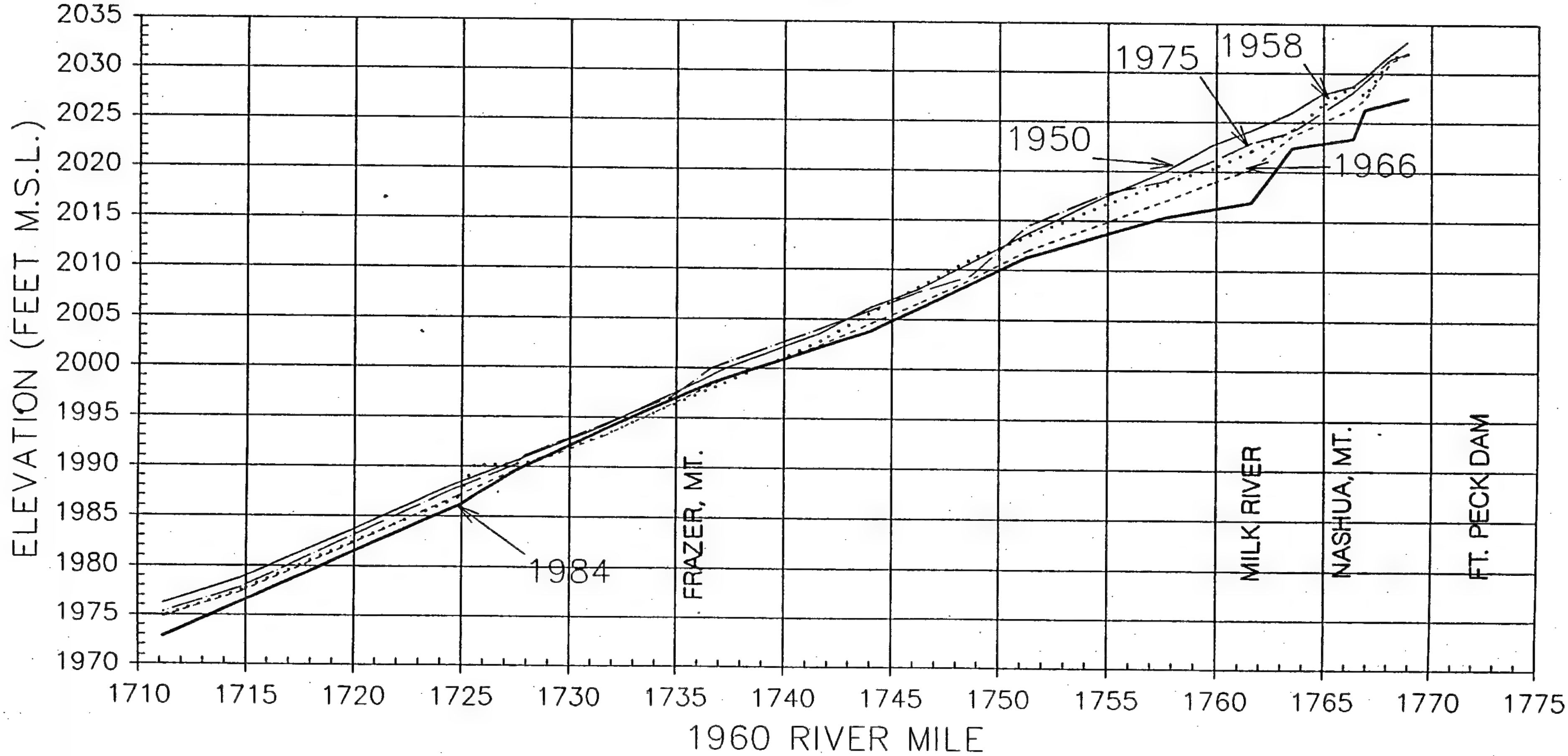
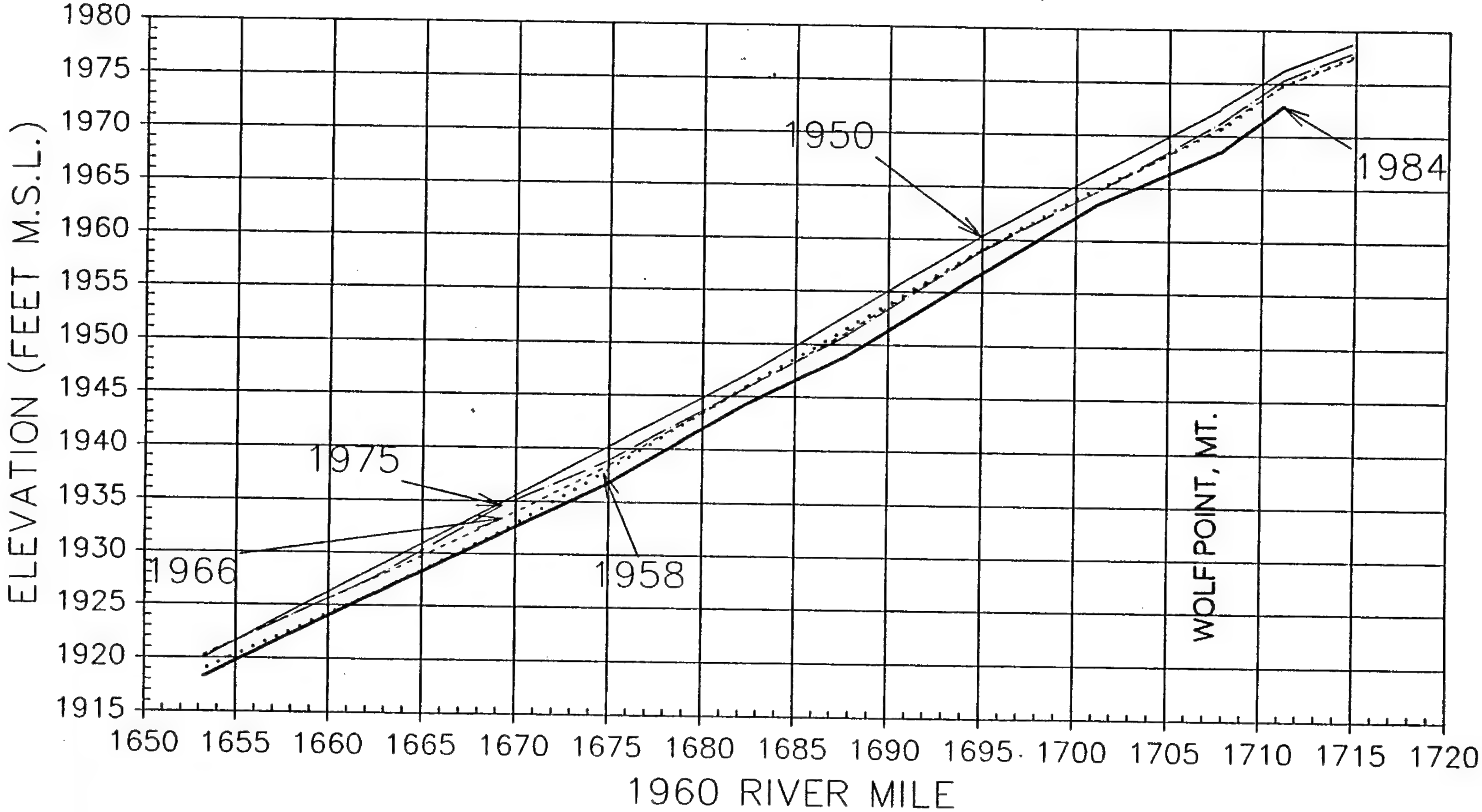

FORT PECK AGGRADATION REACH
D50 GRAIN SIZE DISTRIBUTION
MT. STATE HWY. BRDG. 19
1949
1953
1961
1972
1988
GRAIN SIZE (mm)
1960 RIVER MILE
0
2
4
6
8
10
12
14
16
18
1870
1880
1890
1900
1910
1920
1930
1940

Plate 16

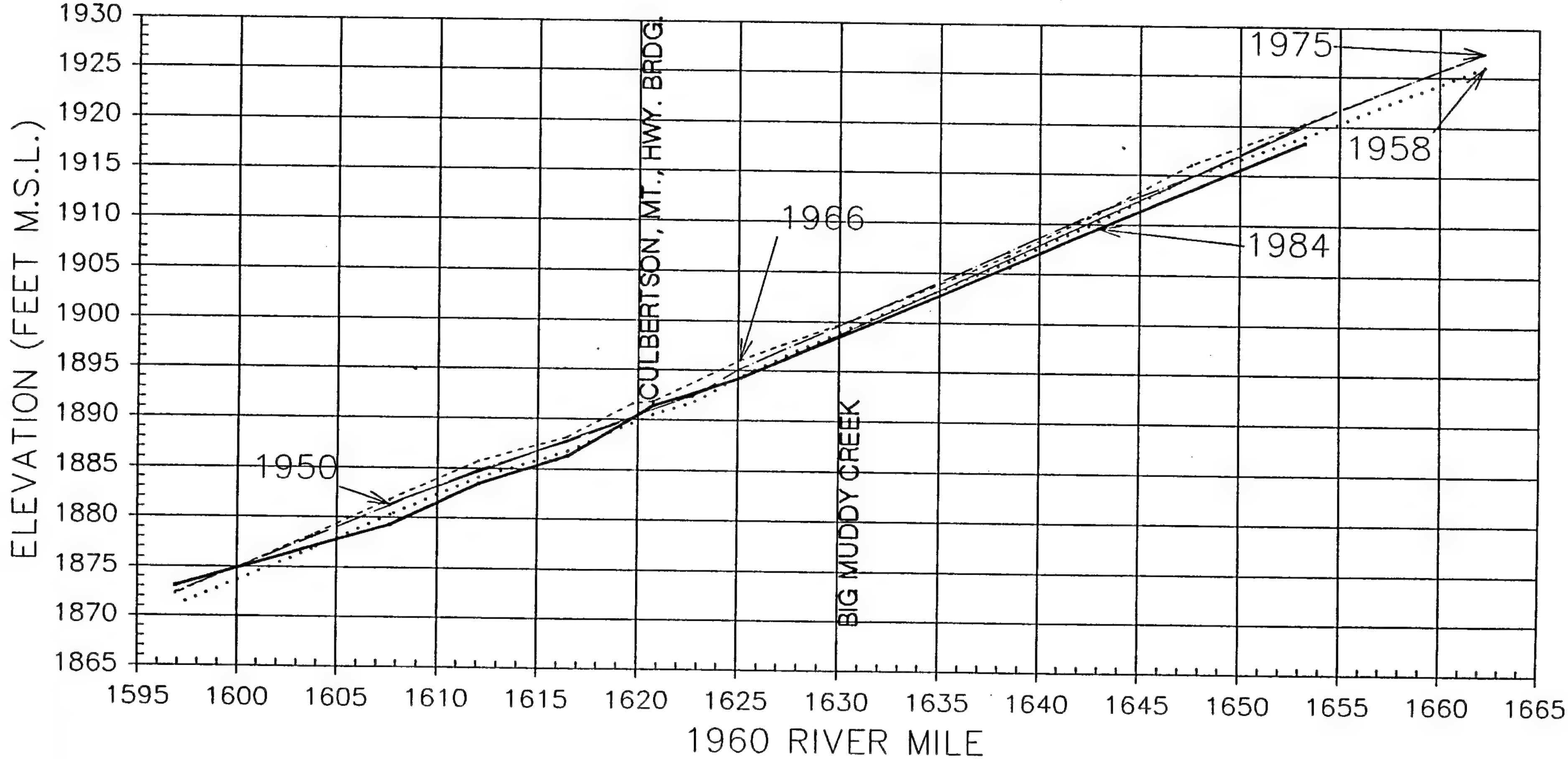
MISSOURI RIVER BELOW FORT PECK DAM
WATER SURFACE PROFILES
ADJUSTED TO DISCHARGE OF 15,000 C.F.S.



MISSOURI RIVER BELOW FORT PECK DAM
WATER SURFACE PROFILES
ADJUSTED TO DISCHARGE OF 15,000 C.F.S.



MISSOURI RIVER BELOW FORT PECK DAM
WATER SURFACE PROFILES
ADJUSTED TO DISCHARGE OF 15,000 C.F.S.



FORT PECK DEGRADATION REACH
STAGE TRENDS
GAGE NO. 1, RM 1768.9 (2.61 mi. downstream from Fort Peck Dam)

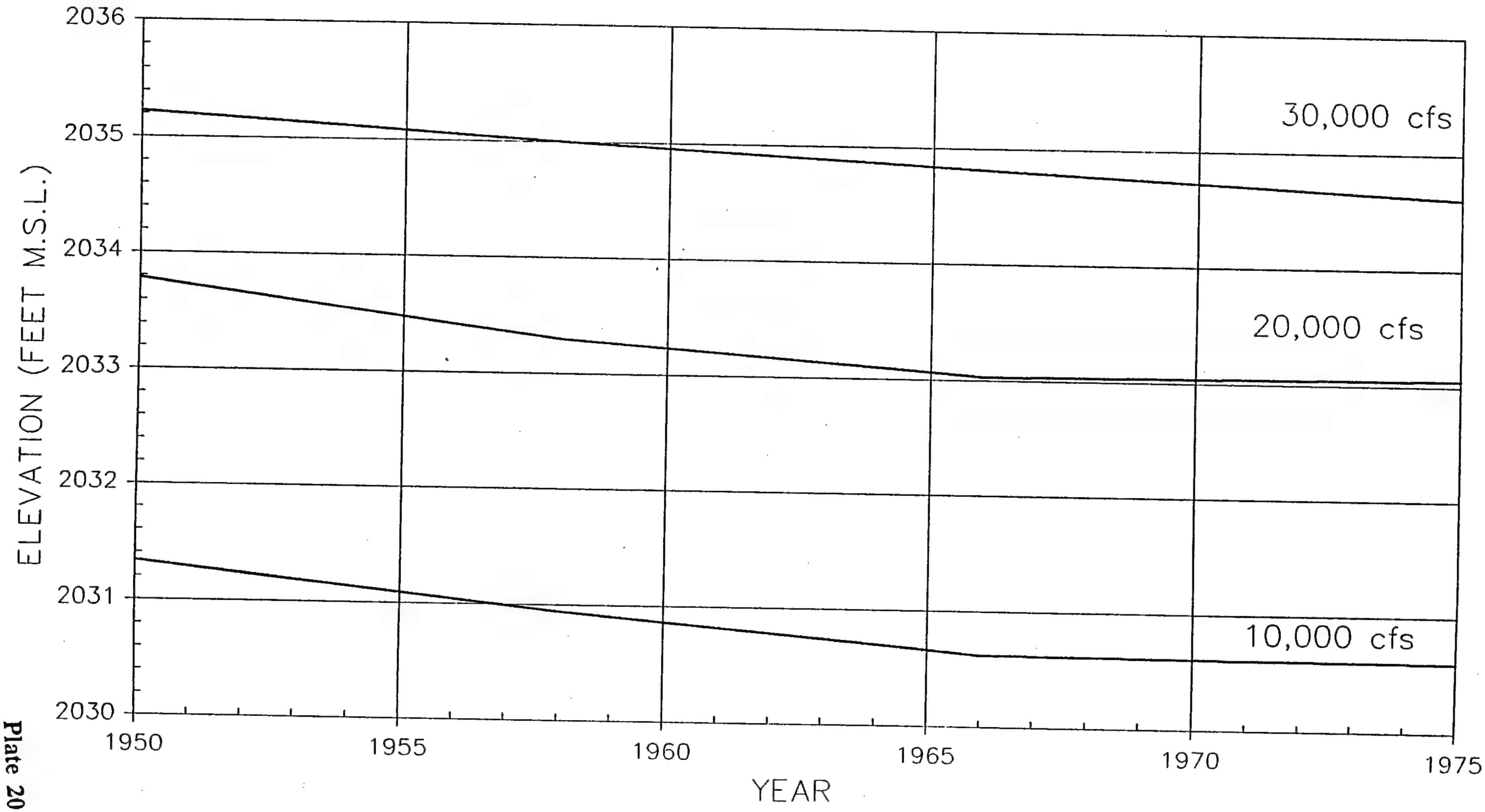
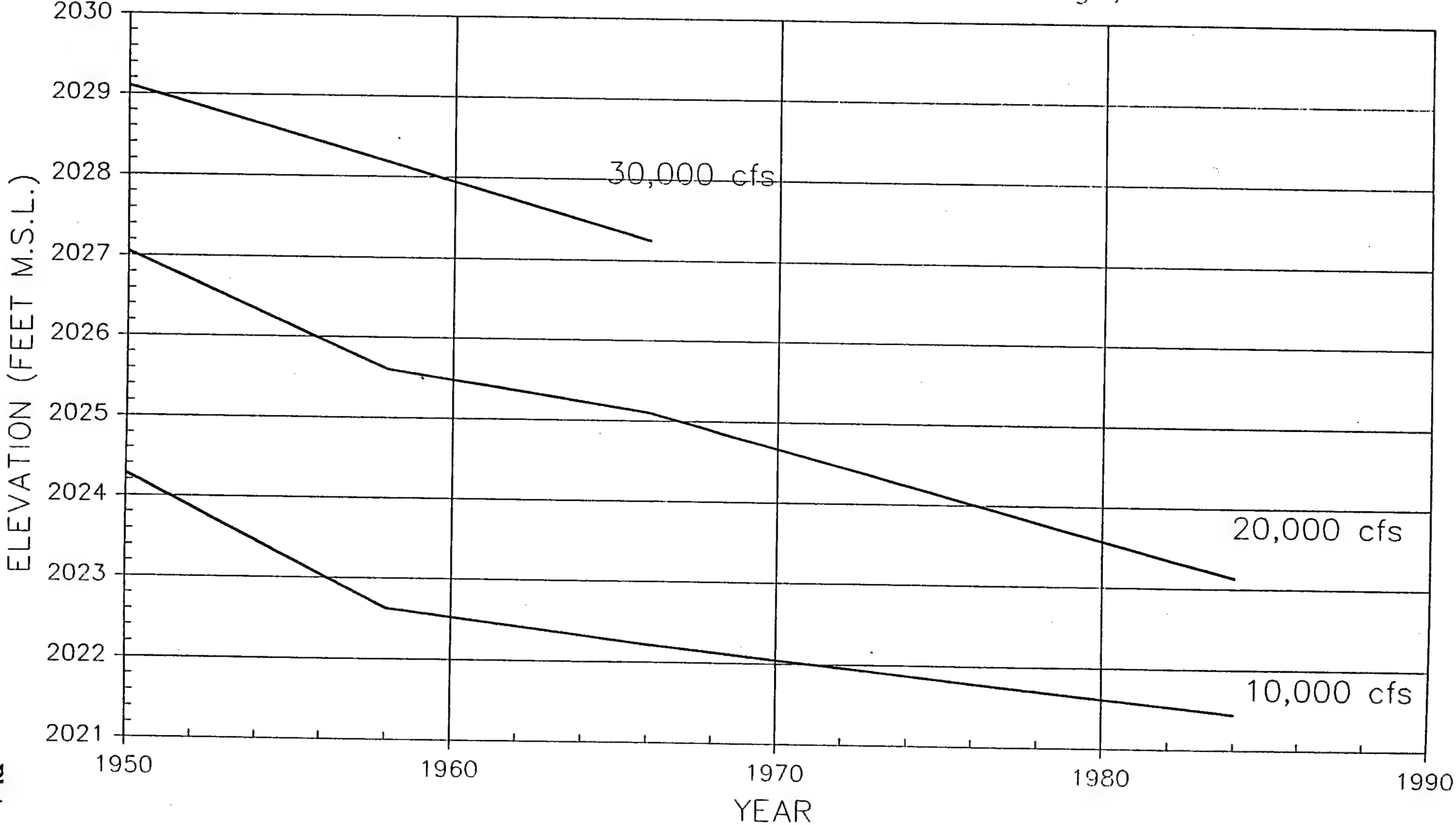


Plate 20

FORT PECK DEGRADATION REACH
STAGE TRENDS
GAGE NO. 2, RM 1763.5 (7 Mile Gage)



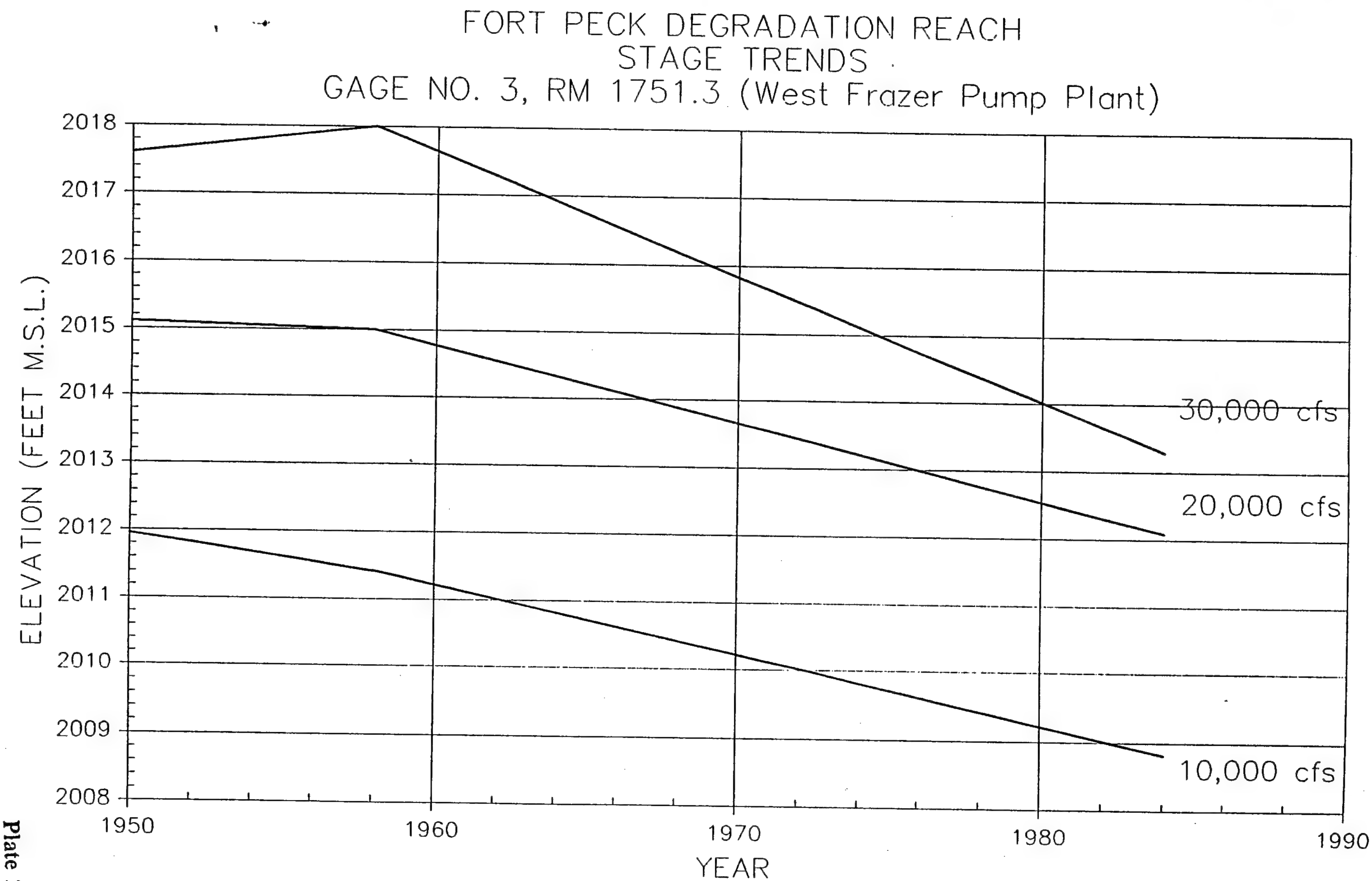
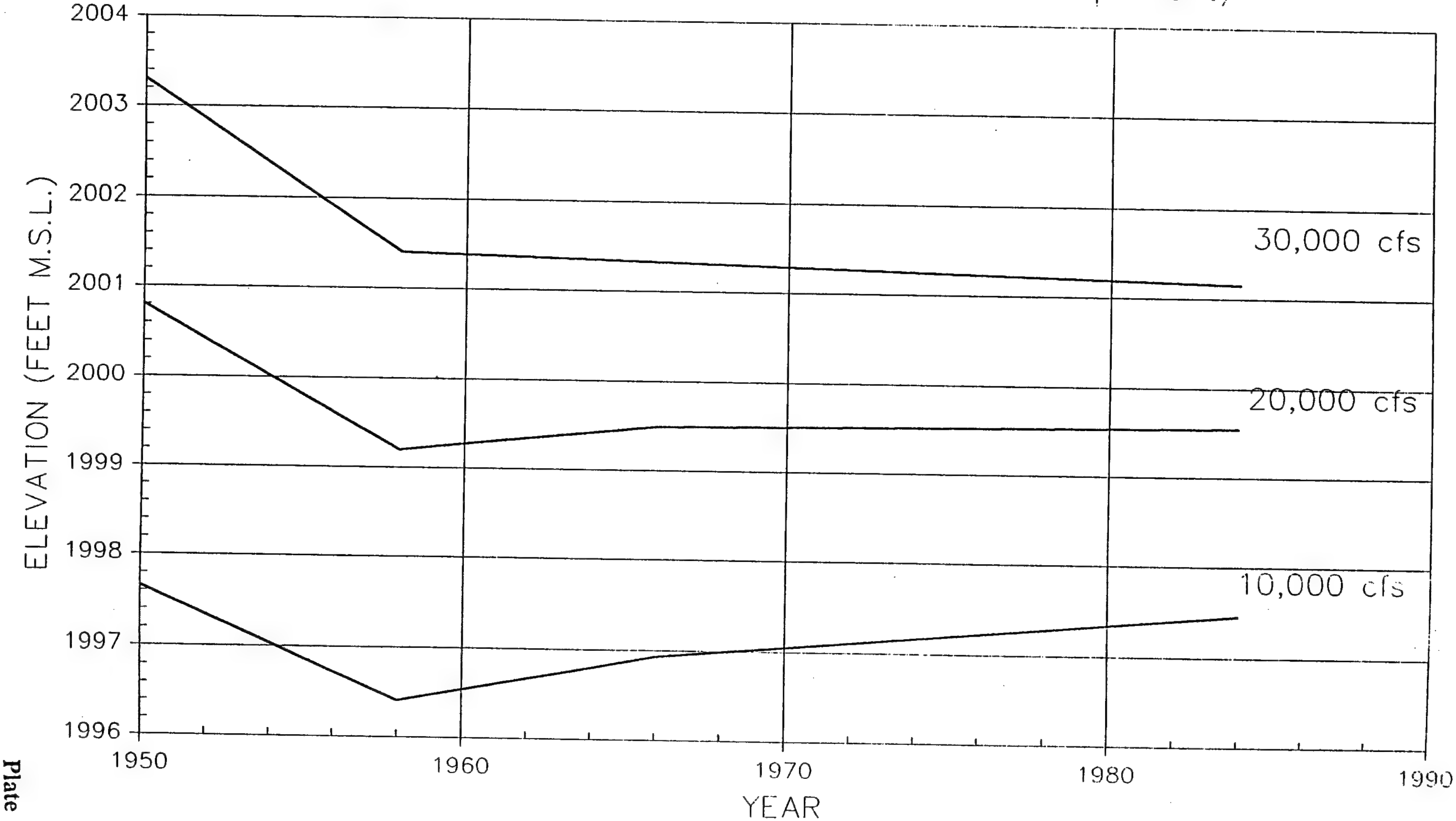
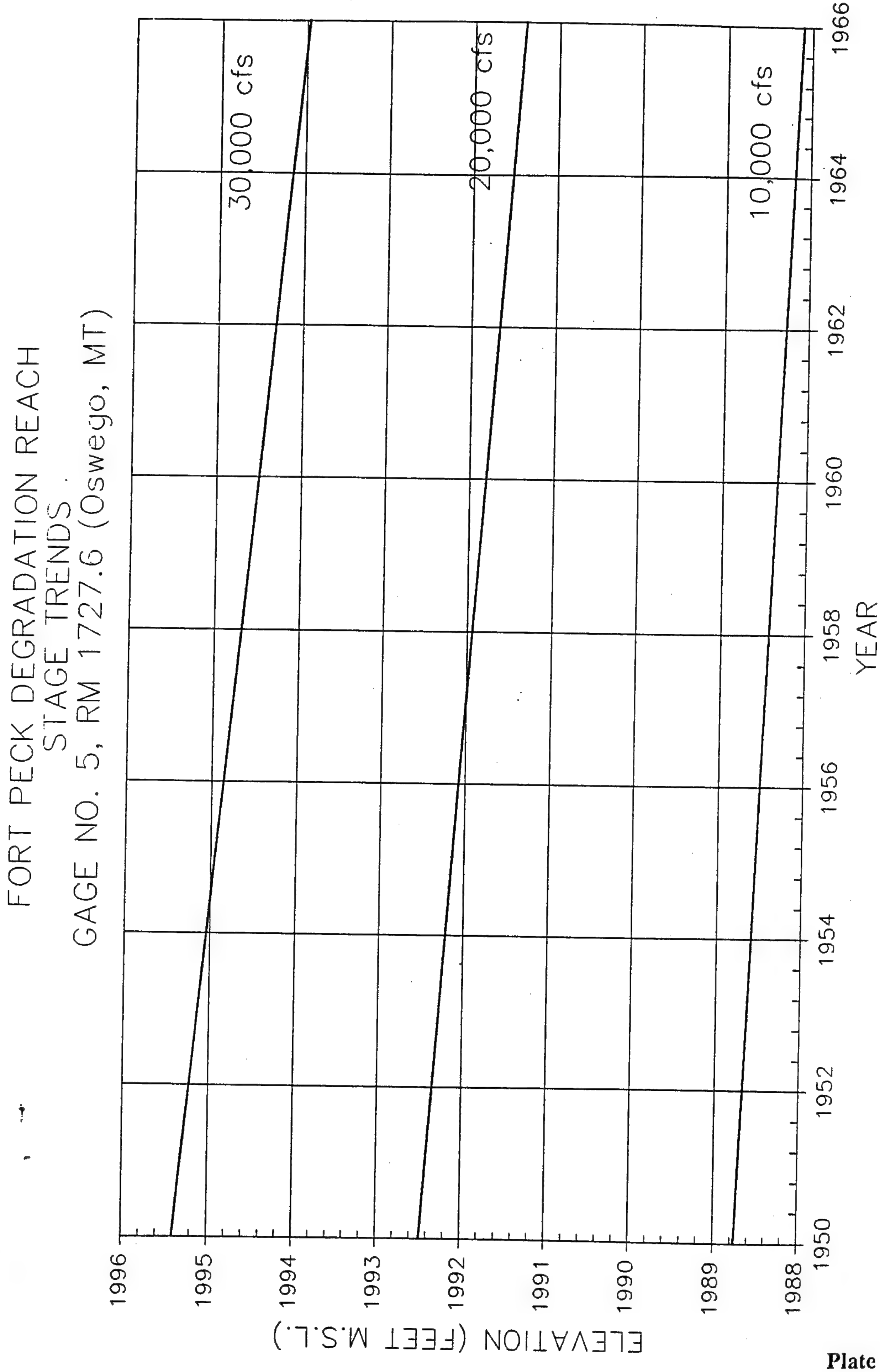

FORT PECK DEGRADATION REACH
STAGE TRENDS
GAGE NO. 3, RM 1751.3 (West Frazer Pump Plant)
ELEVATION (FEET M.S.L.)
2018
2017
2016
2015
2014
2013
2012
2011
2010
2009
2008
1950
1960
1970
1980
1990
YEAR
30,000 cfs
20,000 cfs
10,000 cfs

Plate 22

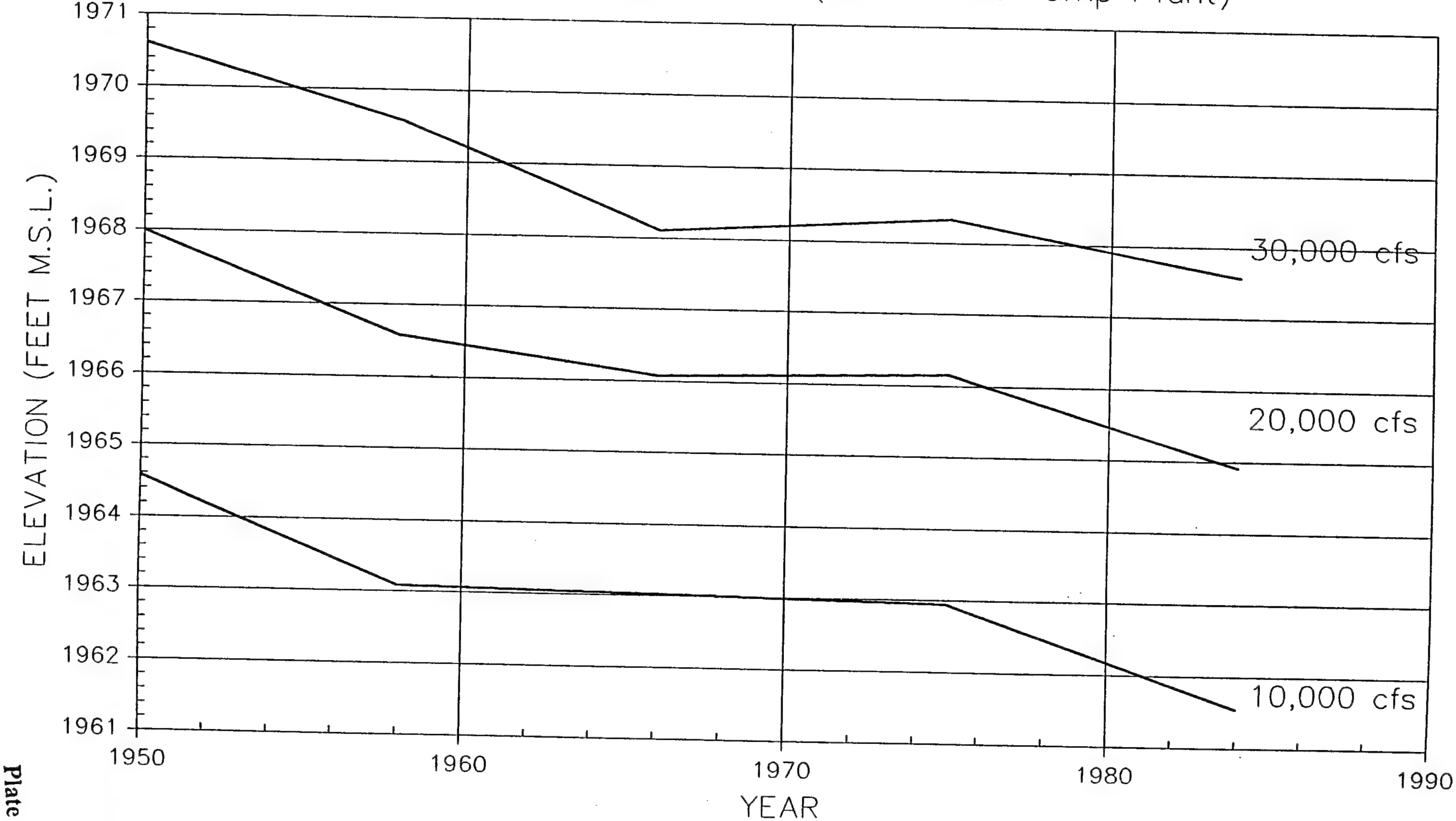
FORT PECK DEGRADATION REACH
STAGE TRENDS
GAGE NO. 4, RM 1736.6 (East Frazer Pump Plant)



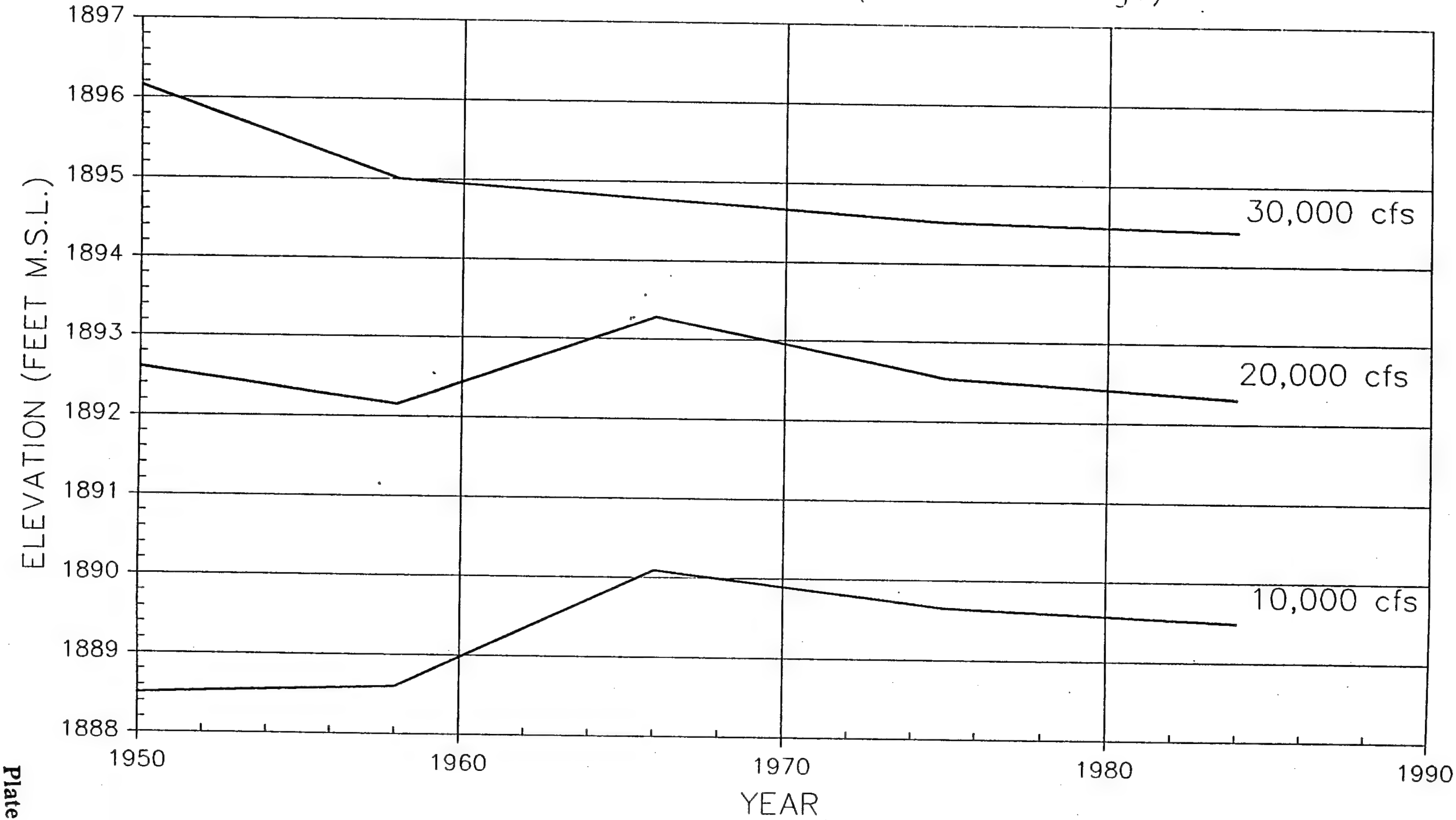


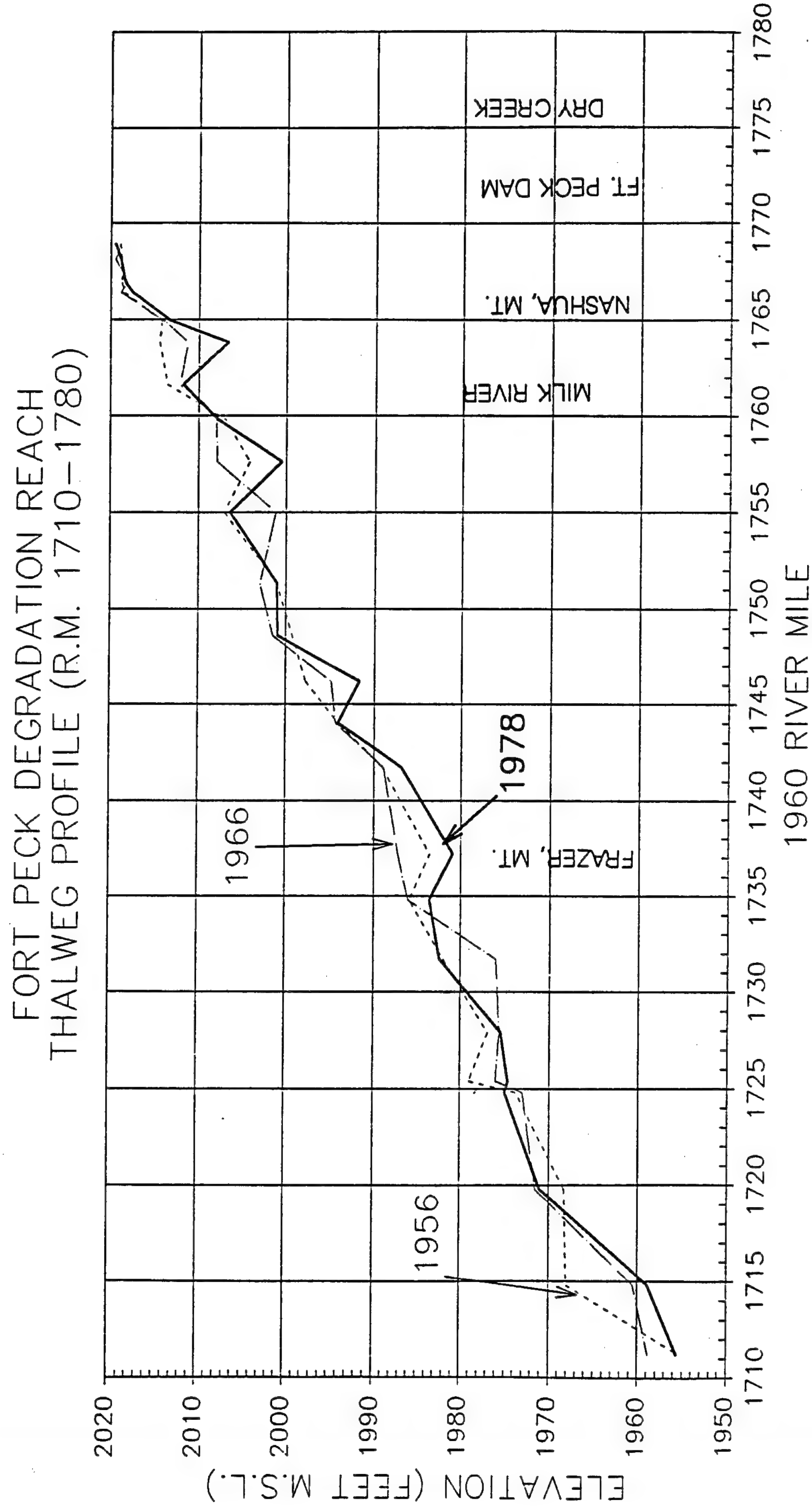
FORT PECK DEGRADATION REACH
STAGE TRENDS
GAGE NO. 5, RM 1727.6 (Oswego, MT)
30,000 cfs
20,000 cfs
10,000 cfs
ELEVATION (FEET M.S.L.)
1996
1995
1994
1993
1992
1991
1990
1989
1988
YEAR
1950
1952
1954
1956
1958
1960
1962
1964
1966

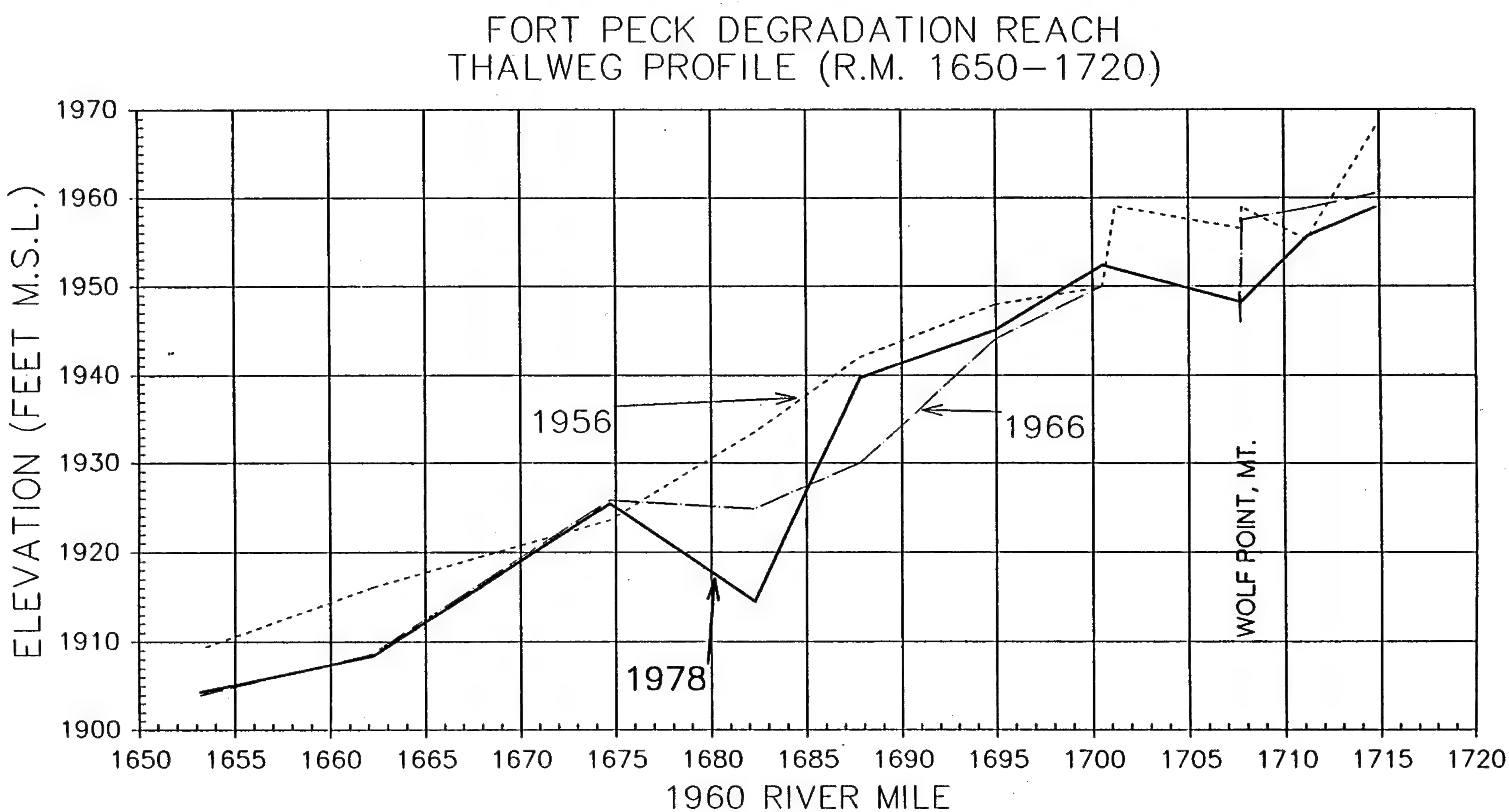
FORT PECK DEGRADATION REACH
STAGE TRENDS
GAGE NO. 6, RM 1701.2 (Wolf Point Pump Plant)

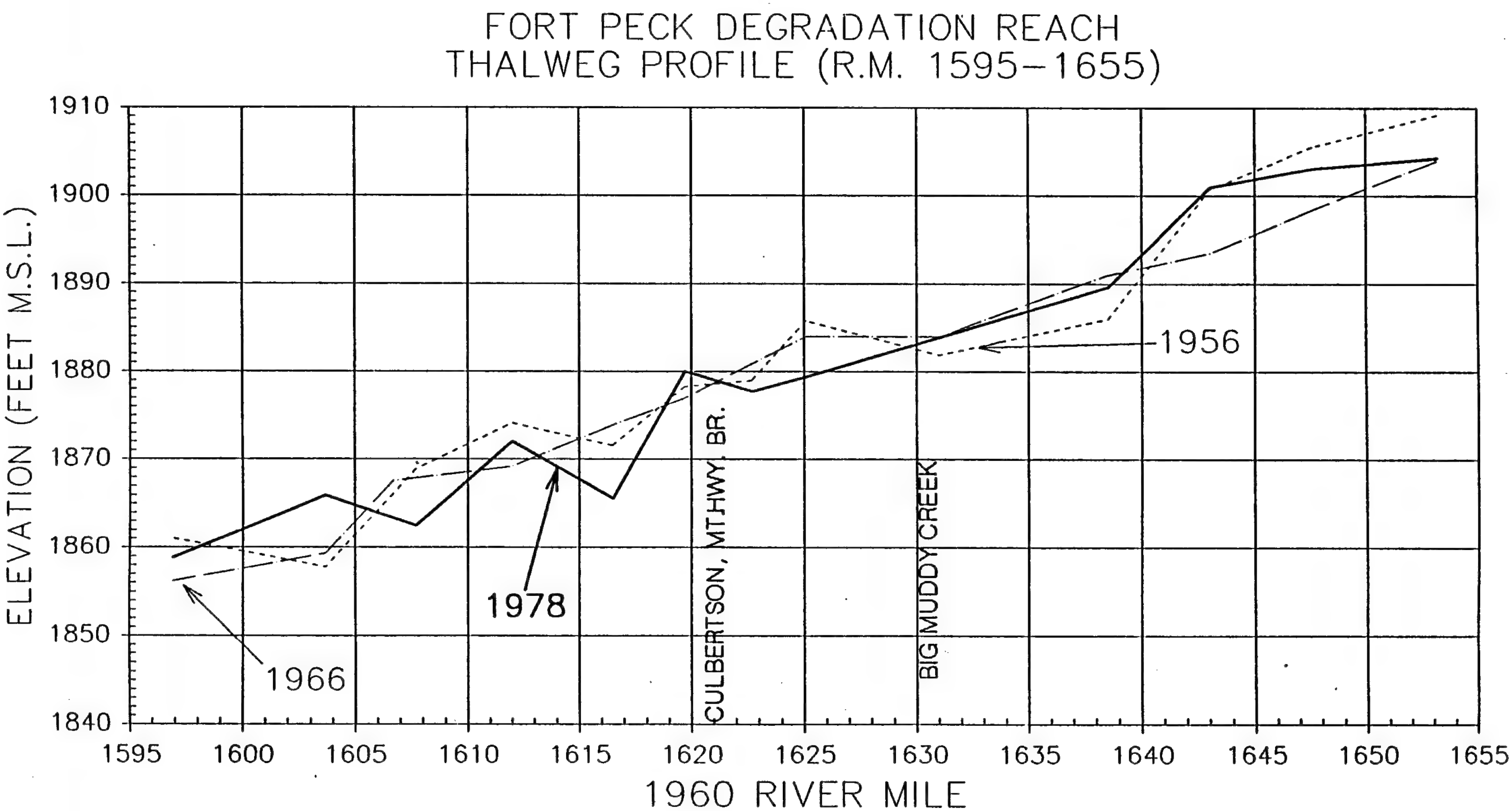


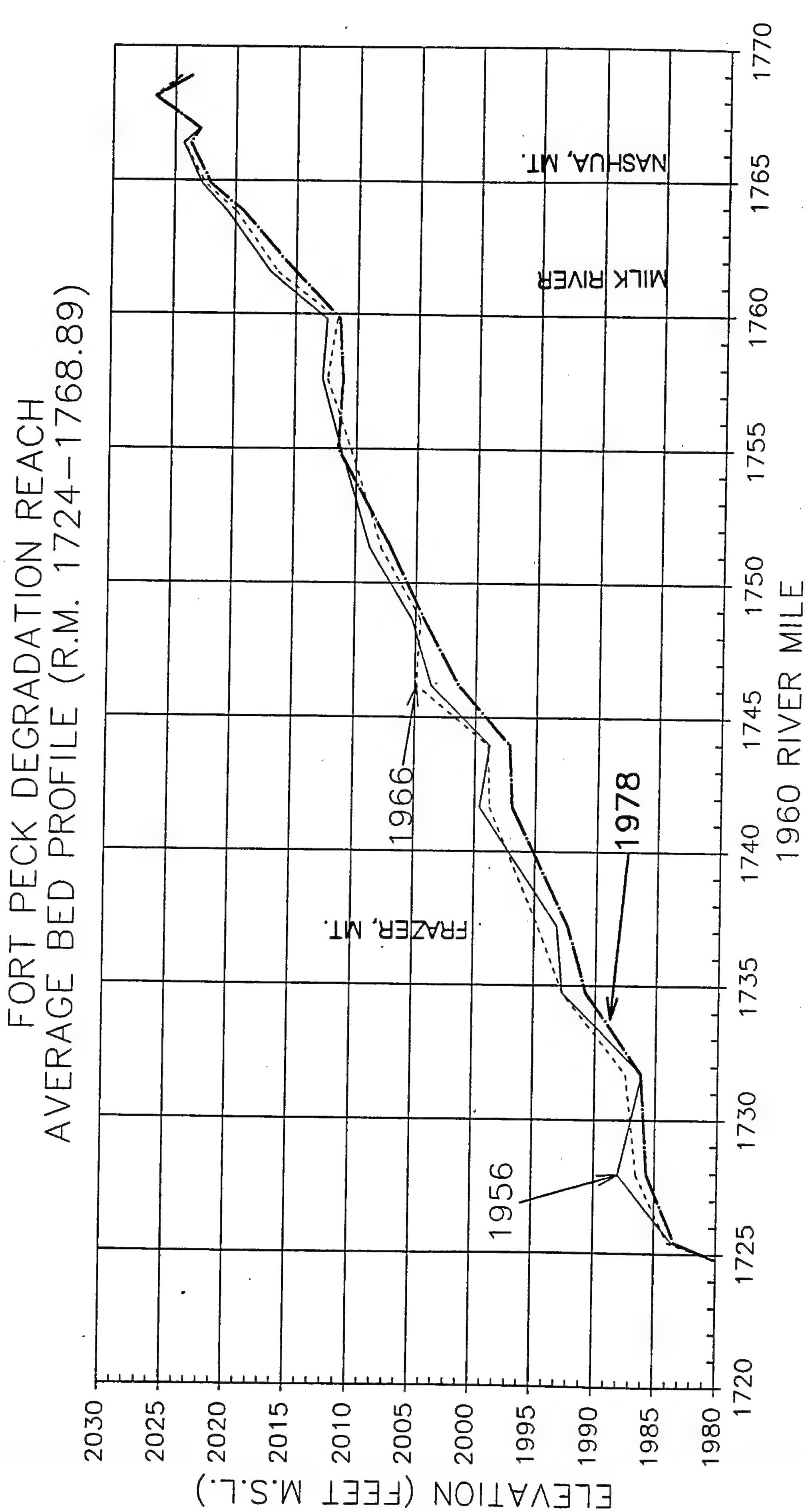
FORT PECK DEGRADATION REACH
STAGE TRENDS
GAGE NO. 7, RM 1620.8 (Culbertson Gage)



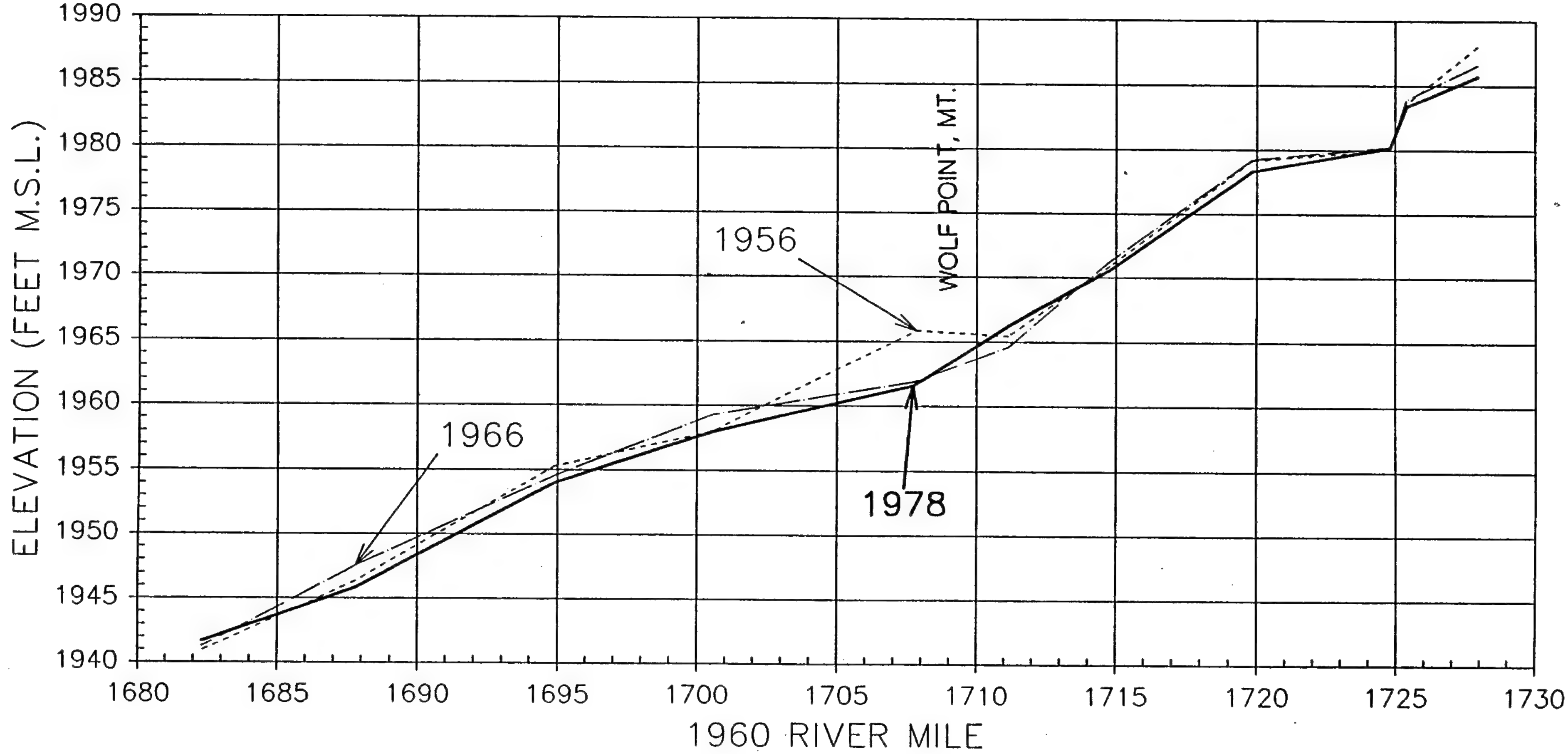

FORT PECK DEGRADATION REACH
THALWEG PROFILE (R.M. 1710–1780)
ELEVATION (FEET M.S.L.)
1960 RIVER MILE
2020
2010
2000
1990
1980
1970
1960
1950
1710
1715
1720
1725
1730
1735
1740
1745
1750
1755
1760
1765
1770
1775
1780
1956
1966
1978
FRAZER, MT.
MILK RIVER
NASHUA, MT.
FT. PECK DAM
DRY CREEK

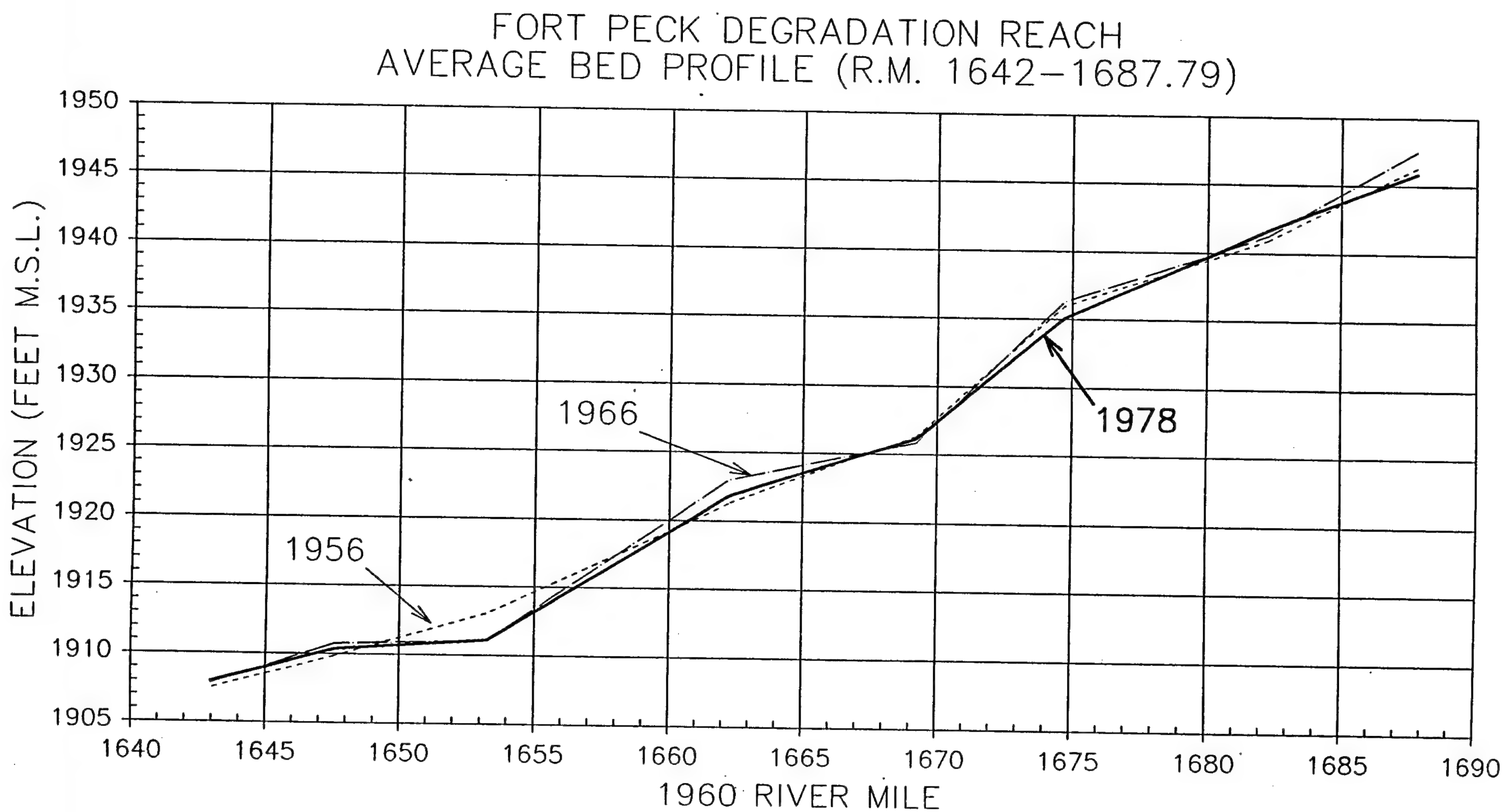

FORT PECK DEGRADATION REACH
THALWEG PROFILE (R.M. 1650–1720)
ELEVATION (FEET M.S.L.)
1970
1960
1950
1940
1930
1920
1910
1900
1650
1655
1660
1665
1670
1675
1680
1685
1690
1695
1700
1705
1710
1715
1720
1960 RIVER MILE
1956
1966
1978
WOLF POINT, MT.


FORT PECK DEGRADATION REACH
THALWEG PROFILE (R.M. 1595–1655)
ELEVATION (FEET M.S.L.)
1910
1900
1890
1880
1870
1860
1850
1840
1595
1600
1605
1610
1615
1620
1625
1630
1635
1640
1645
1650
1655
1960 RIVER MILE
1956
1966
1978
CULBERTSON, MT.HWY. BR.
BIG MUDDY CREEK

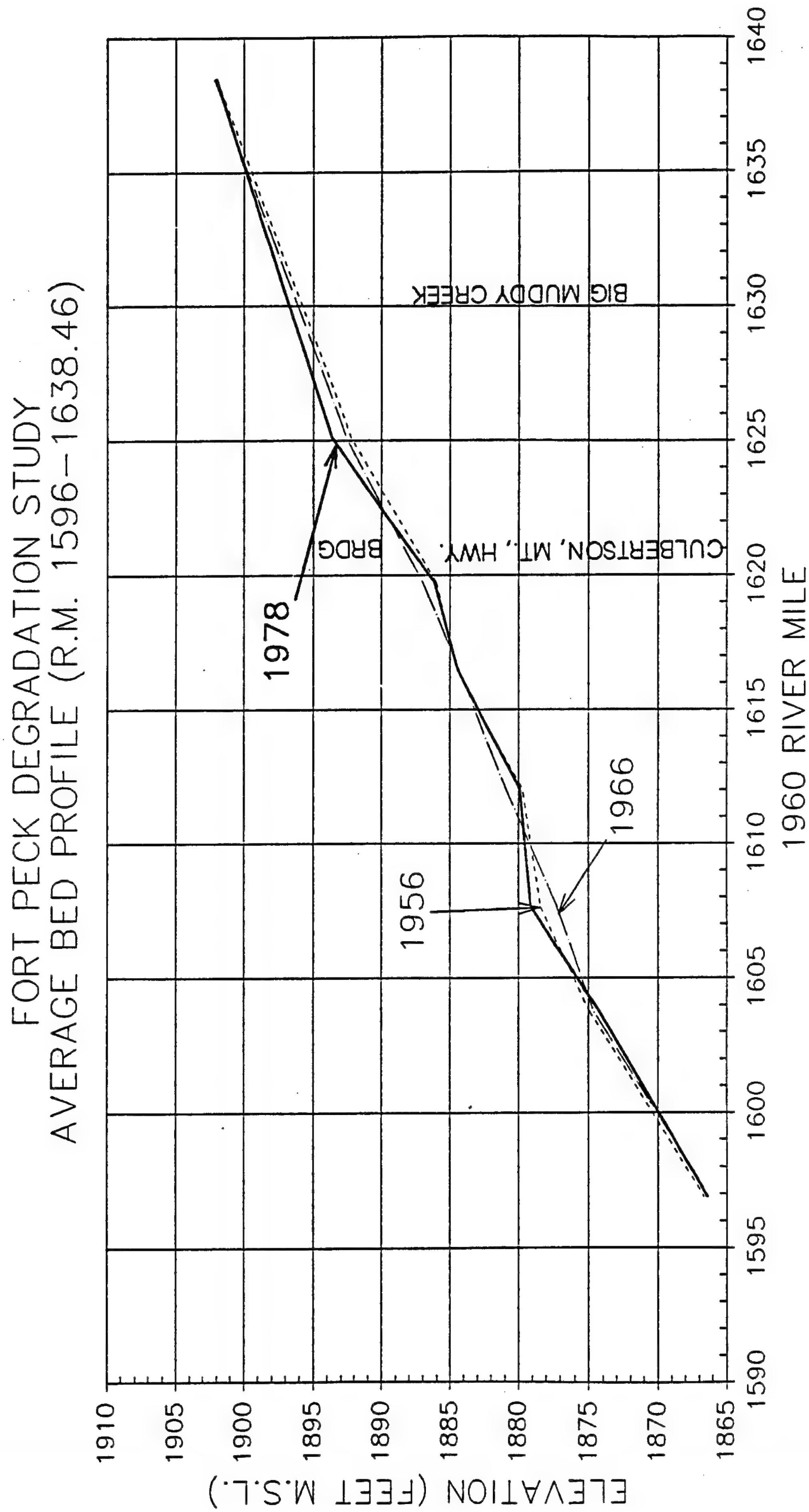

FORT PECK DEGRADATION REACH
AVERAGE BED PROFILE (R.M. 1724–1768.89)
ELEVATION (FEET M.S.L.)
1960 RIVER MILE
1956
1966
1978
FRAZER, MT.
MILK RIVER
NASHUA, MT.
2030
2025
2020
2015
2010
2005
2000
1995
1990
1985
1980
1720
1725
1730
1735
1740
1745
1750
1755
1760
1765
1770

FORT PECK DEGRADATION REACH
AVERAGE BED PROFILE (R.M. 1682–1727.94)



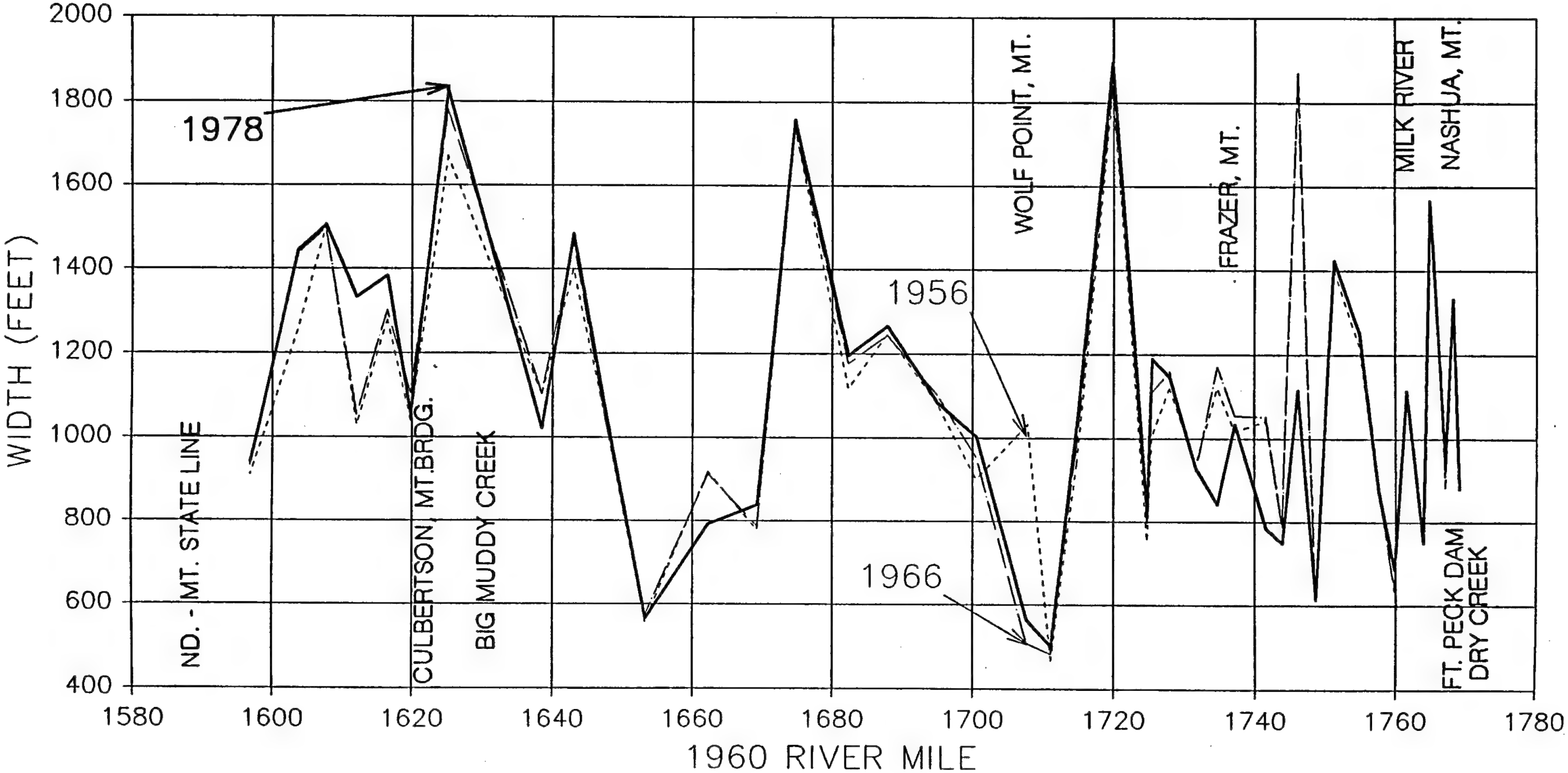


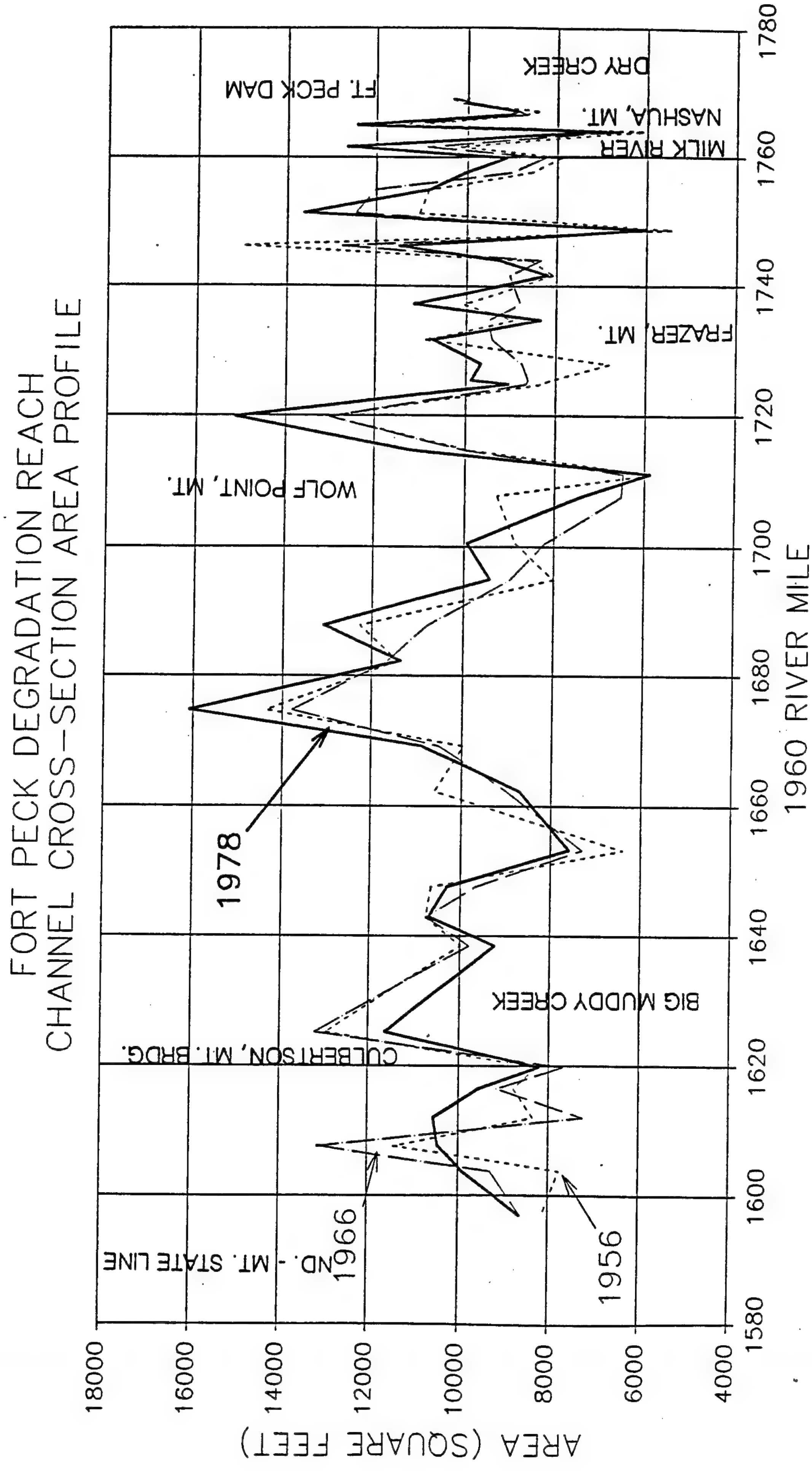
FORT PECK DEGRADATION REACH
AVERAGE BED PROFILE (R.M. 1642–1687.79)
ELEVATION (FEET M.S.L.)
1950
1945
1940
1935
1930
1925
1920
1915
1910
1905
1640
1645
1650
1655
1660
1665
1670
1675
1680
1685
1690
1960 RIVER MILE
1956
1966
1978



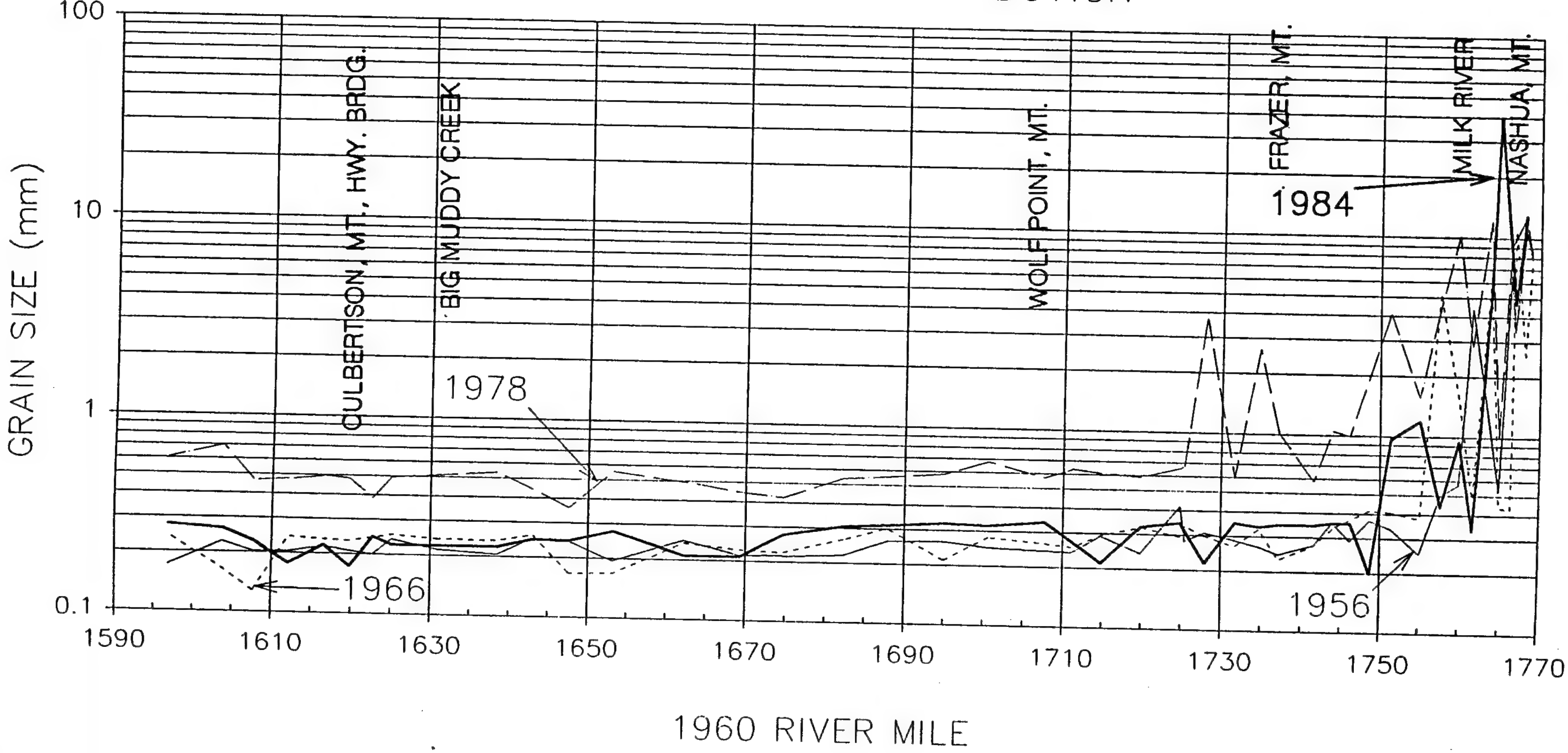
FORT PECK DEGRADATION STUDY
AVERAGE BED PROFILE (R.M. 1596–1638.46)
ELEVATION (FEET M.S.L.)
1960 RIVER MILE
1910
1905
1900
1895
1890
1885
1880
1875
1870
1865
1590
1595
1600
1605
1610
1615
1620
1625
1630
1635
1640
BIG MUDDY CREEK
CULBERTSON, MT., HWY. BRDG
1978
1966
1956

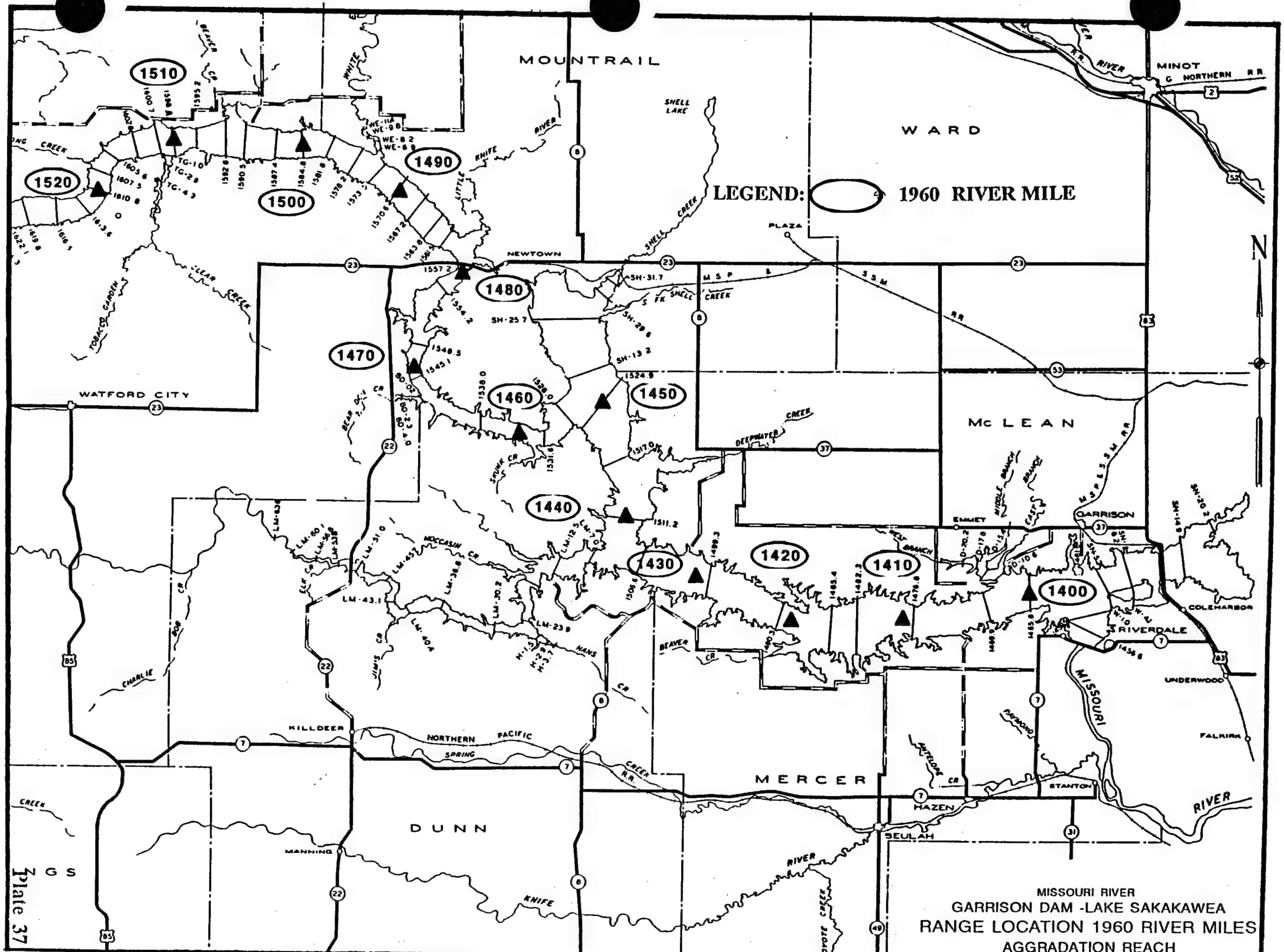
FORT PECK DEGRADATION REACH
CHANNEL WIDTH PROFILE




FORT PECK DEGRADATION REACH
CHANNEL CROSS-SECTION AREA PROFILE
AREA (SQUARE FEET)
18000
16000
14000
12000
10000
8000
6000
4000
1960 RIVER MILE
1580
1600
1620
1640
1660
1680
1700
1720
1740
1760
1780
ND. - MT. STATE LINE
1966
1956
CULBERTSON, MT. BRDG.
BIG MUDDY CREEK
1978
WOLF POINT, MT.
FRAZER, MT.
MILK RIVER
NASHUA, MT.
FT. PECK DAM
DRY CREEK

FORT PECK DEGRADATON REACH
D50 GRAIN SIZE DISTRIBUTION





MISSOURI RIVER
GARRISON DAM -LAKE SAKAKAWEA
RANGE LOCATION 1960 RIVER MILES
AGGRADATION REACH

Plate 37

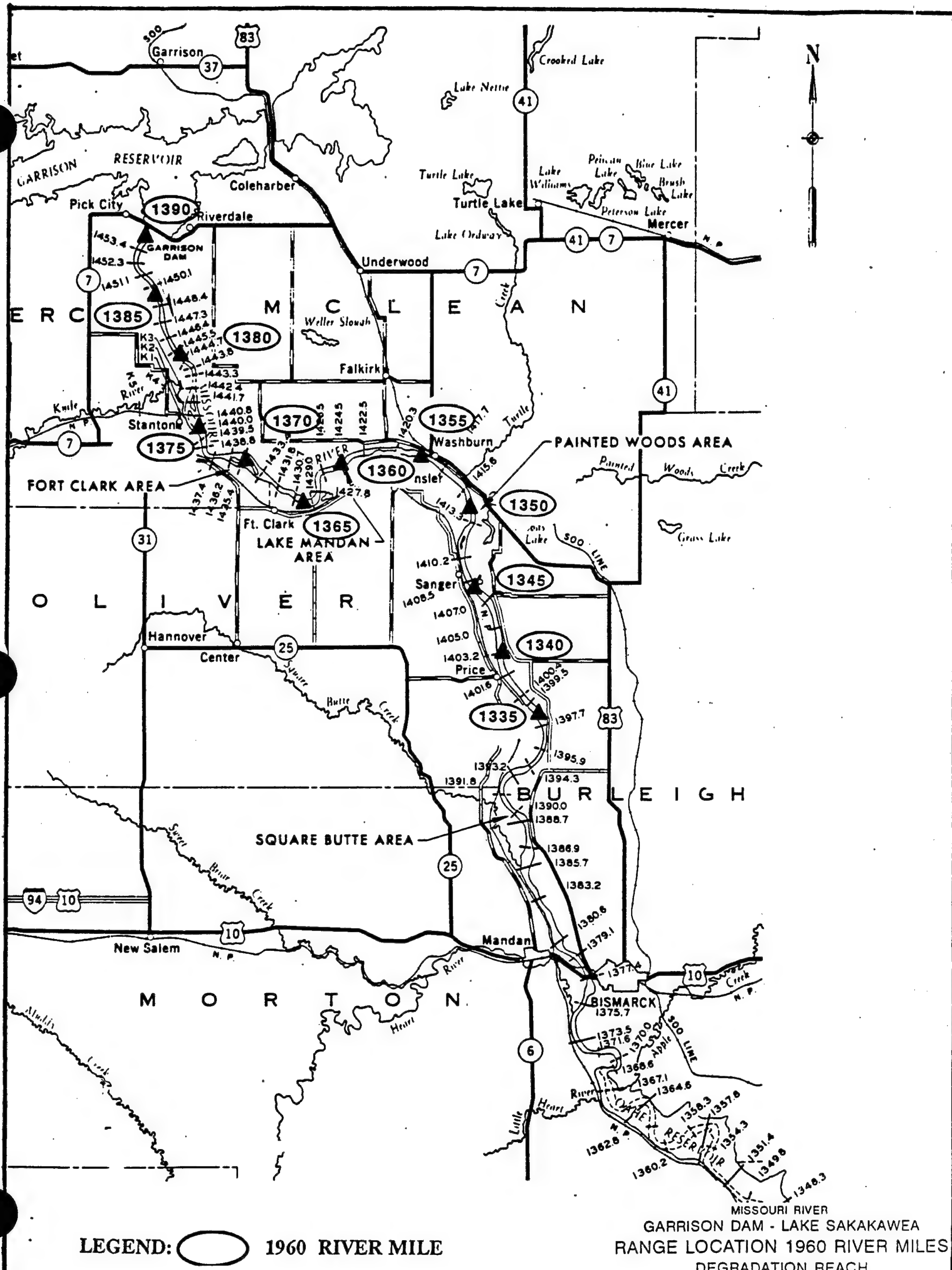
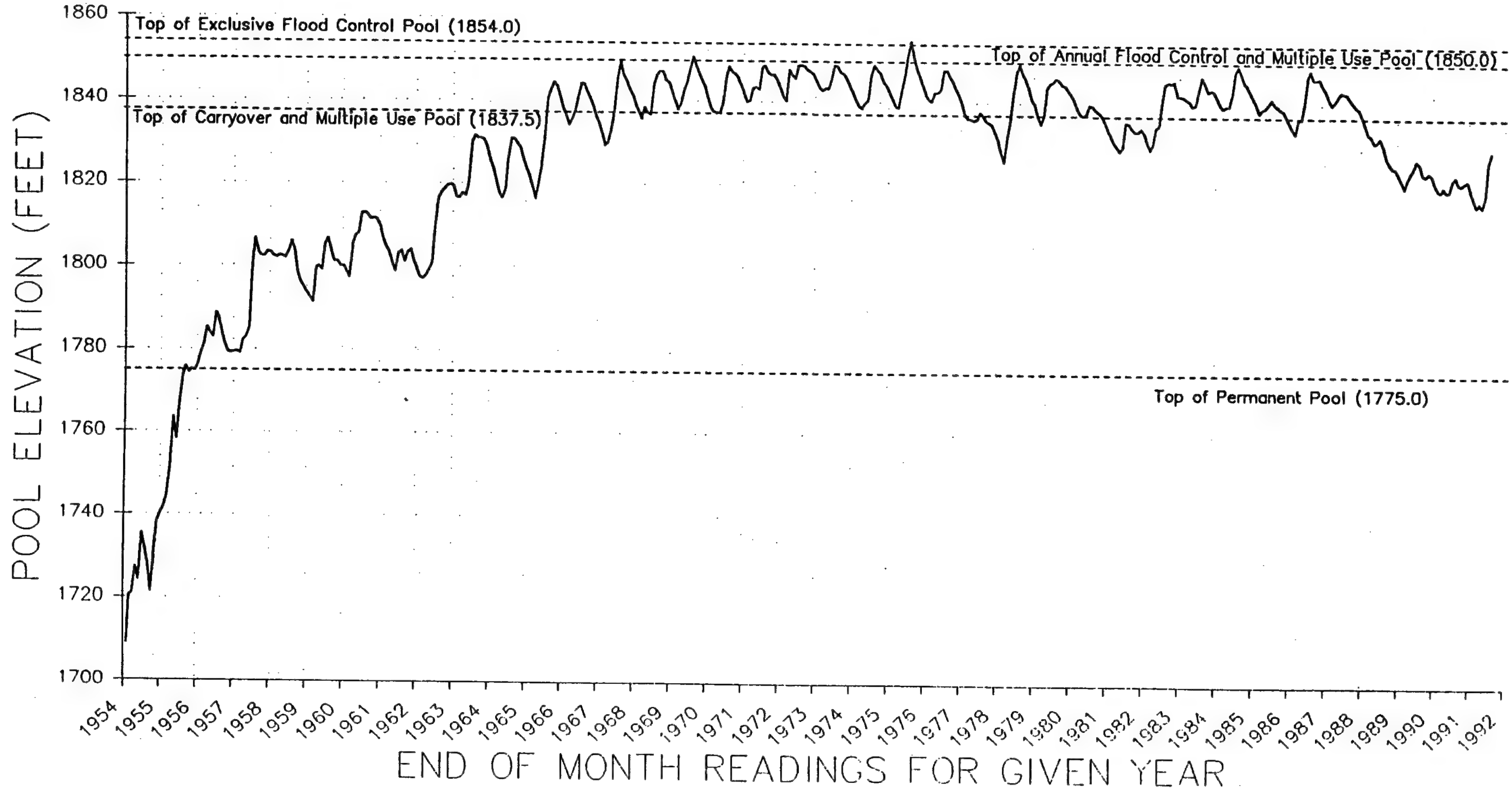

Garrison
GARRISON RESERVOIR
Coleharber
Pick City
1390
Riverdale
GARRISON DAM
Underwood
Turtle Lake
Mercer
M C L E A N
1385
1380
1375
1370
1365
1360
1355
1350
1345
1340
1335
Falkirk
Stanton
Washburn
PAINTED WOODS AREA
FORT CLARK AREA
Ft. Clark
LAKE MANDAN AREA
Sanger
Price
O L I V E R
Hannover
Center
B U R L E I G H
SQUARE BUTTE AREA
New Salem
Mandan
BISMARCK
M O R T O N
LEGEND:
1960 RIVER MILE
MISSOURI RIVER
GARRISON DAM - LAKE SAKAKAWEA
RANGE LOCATION 1960 RIVER MILES
DEGRADATION REACH

Plate 38

END-OF-MONTH POOL ELEVATIONS
GARRISON DAM-LAKE SAKAKAWEA



GARRISON AGGRADATION REACH
THALWEG PROFILE

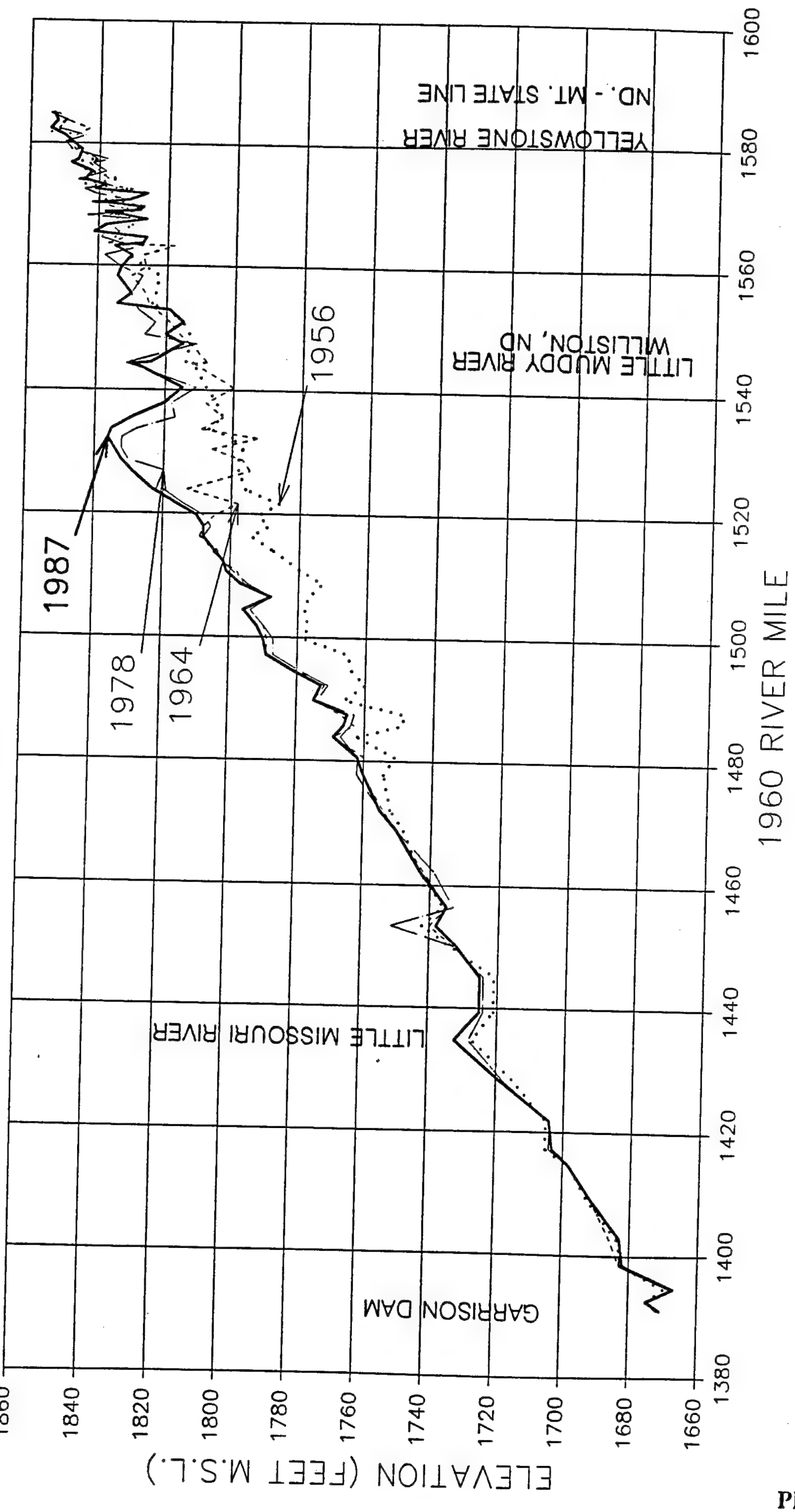
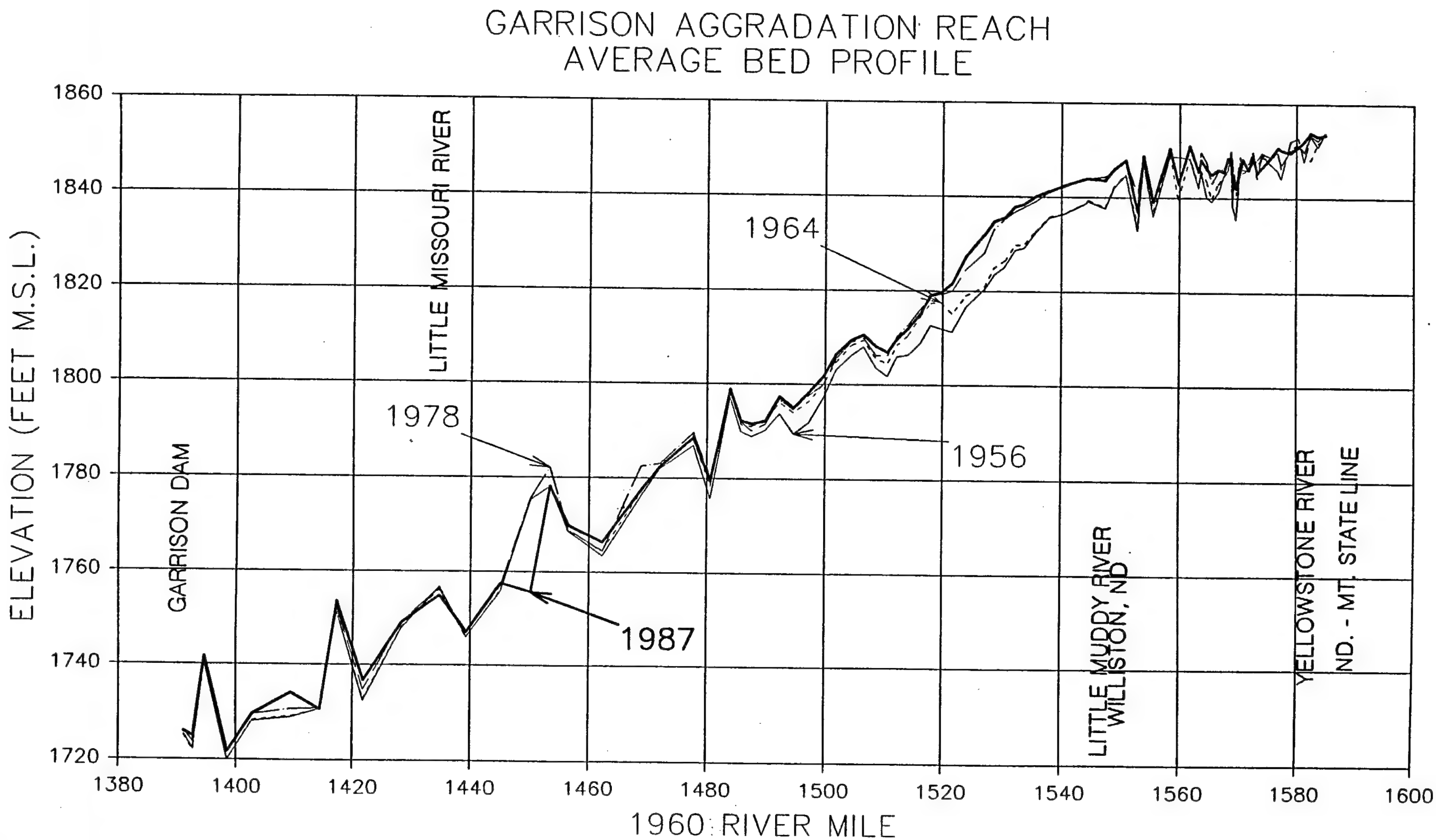
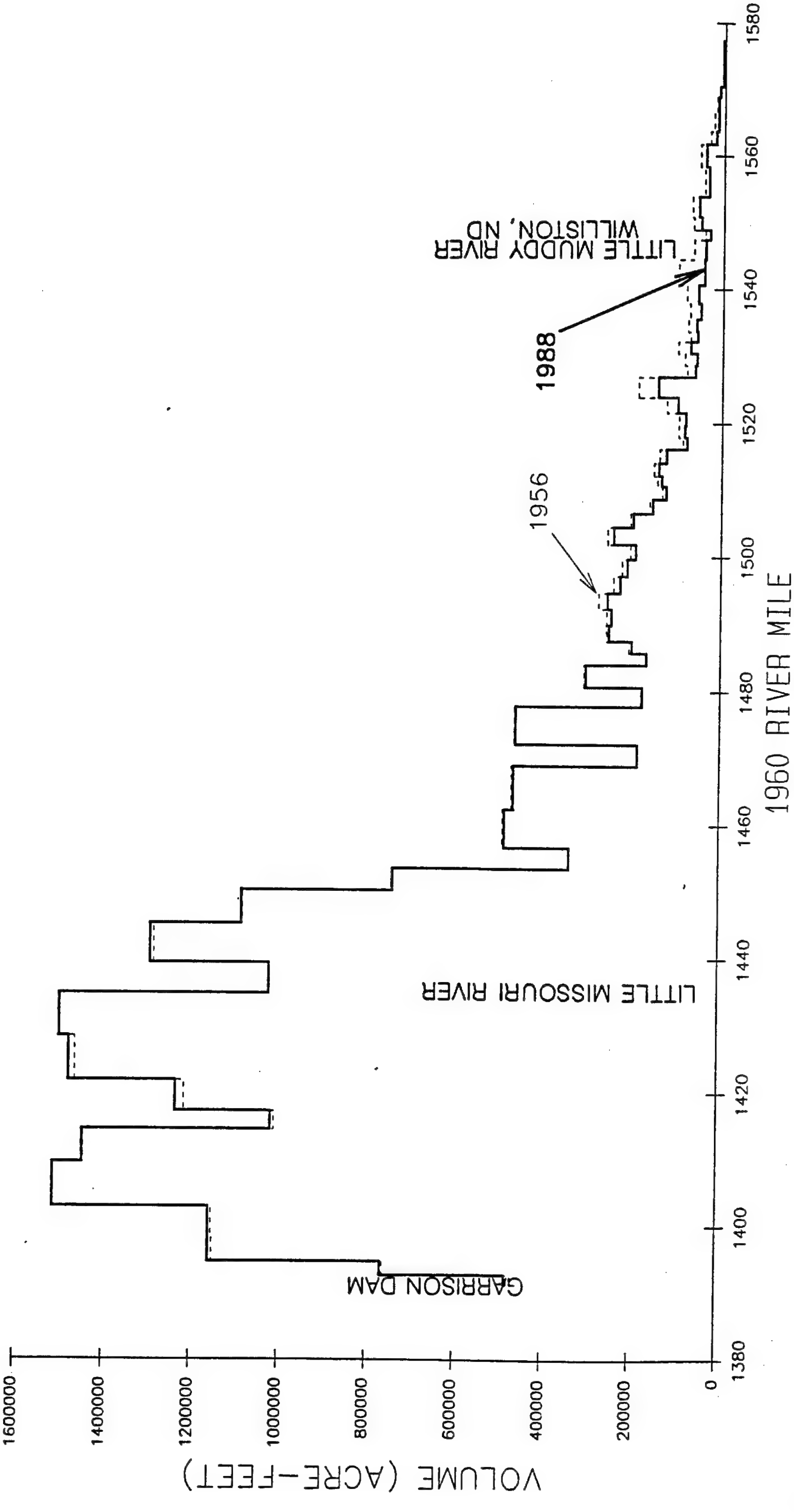
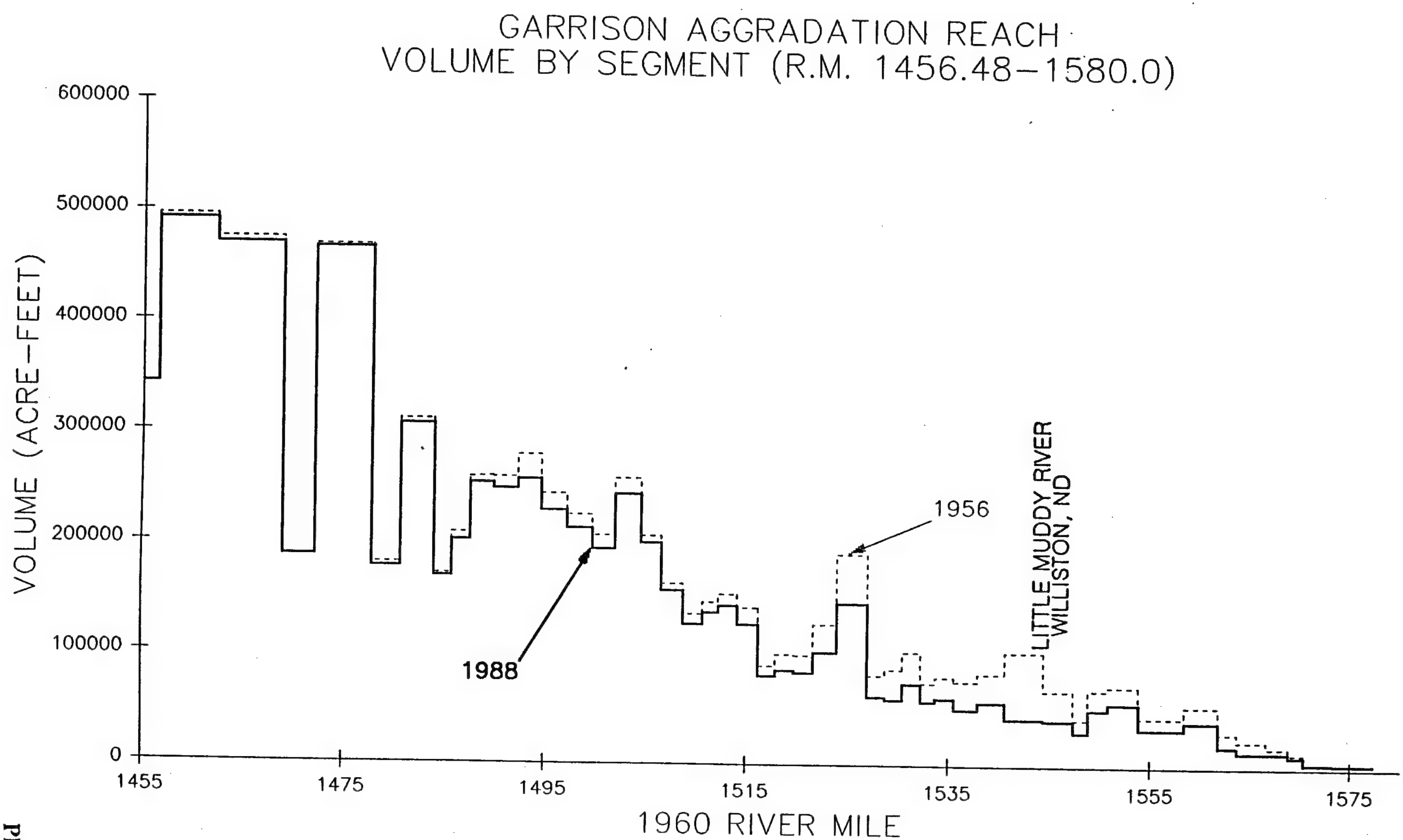


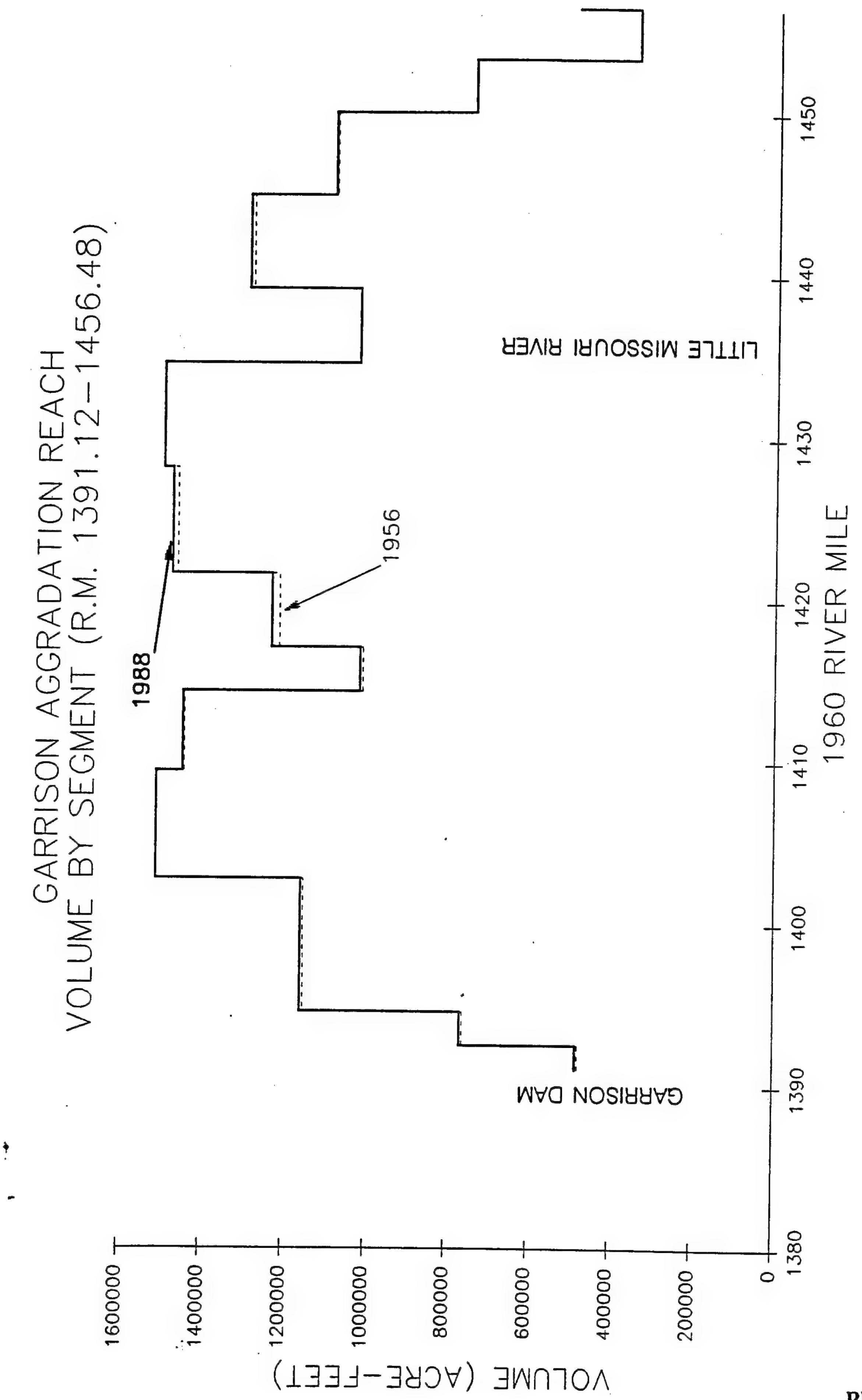
Plate 40


GARRISON AGGRADATION REACH
AVERAGE BED PROFILE
ELEVATION (FEET M.S.L.)
1860
1840
1820
1800
1780
1760
1740
1720
1380
1400
1420
1440
1460
1480
1500
1520
1540
1560
1580
1600
1960 RIVER MILE
GARRISON DAM
LITTLE MISSOURI RIVER
LITTLE MUDDY RIVER
WILLISTON, ND
YELLOWSTONE RIVER
ND. - MT. STATE LINE
1964
1978
1956
1987

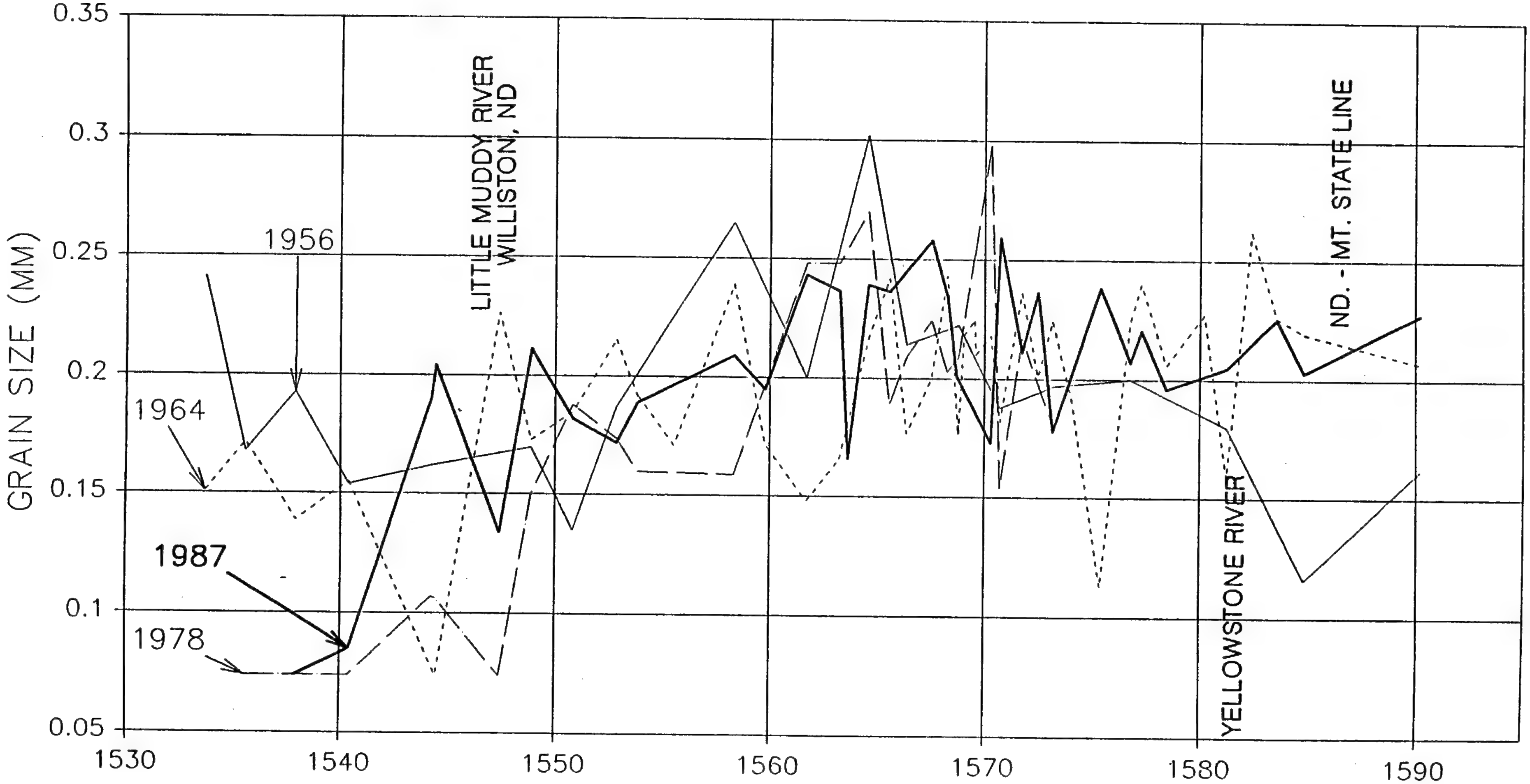
GARRISON AGGRADATION REACH
VOLUME BY SEGMENT



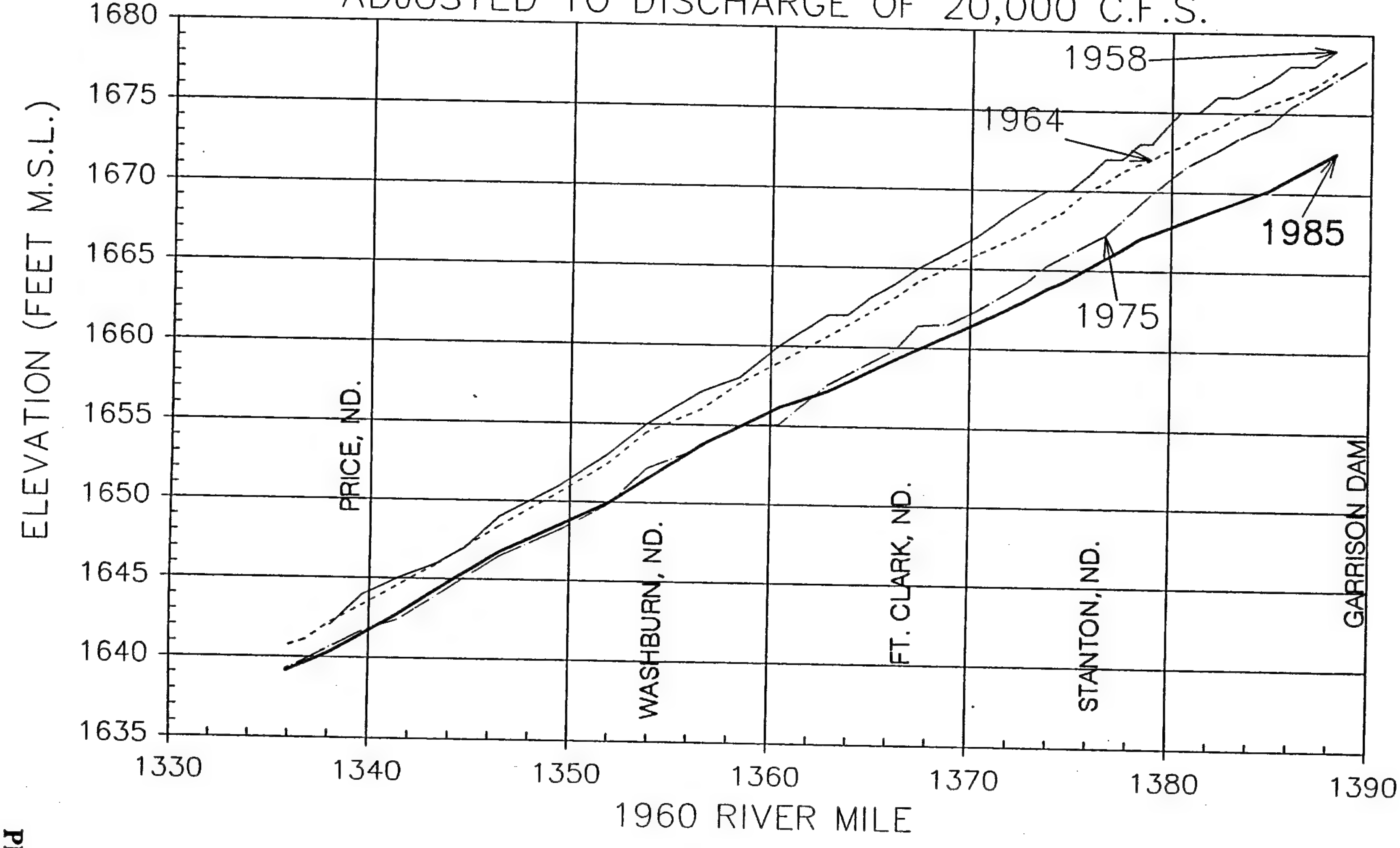

GARRISON AGGRADATION REACH
VOLUME BY SEGMENT (R.M. 1456.48–1580.0)
VOLUME (ACRE–FEET)
600000
500000
400000
300000
200000
100000
0
1455
1475
1495
1515
1535
1555
1575
1960 RIVER MILE
1988
1956
LITTLE MUDDY RIVER
WILLISTON, ND

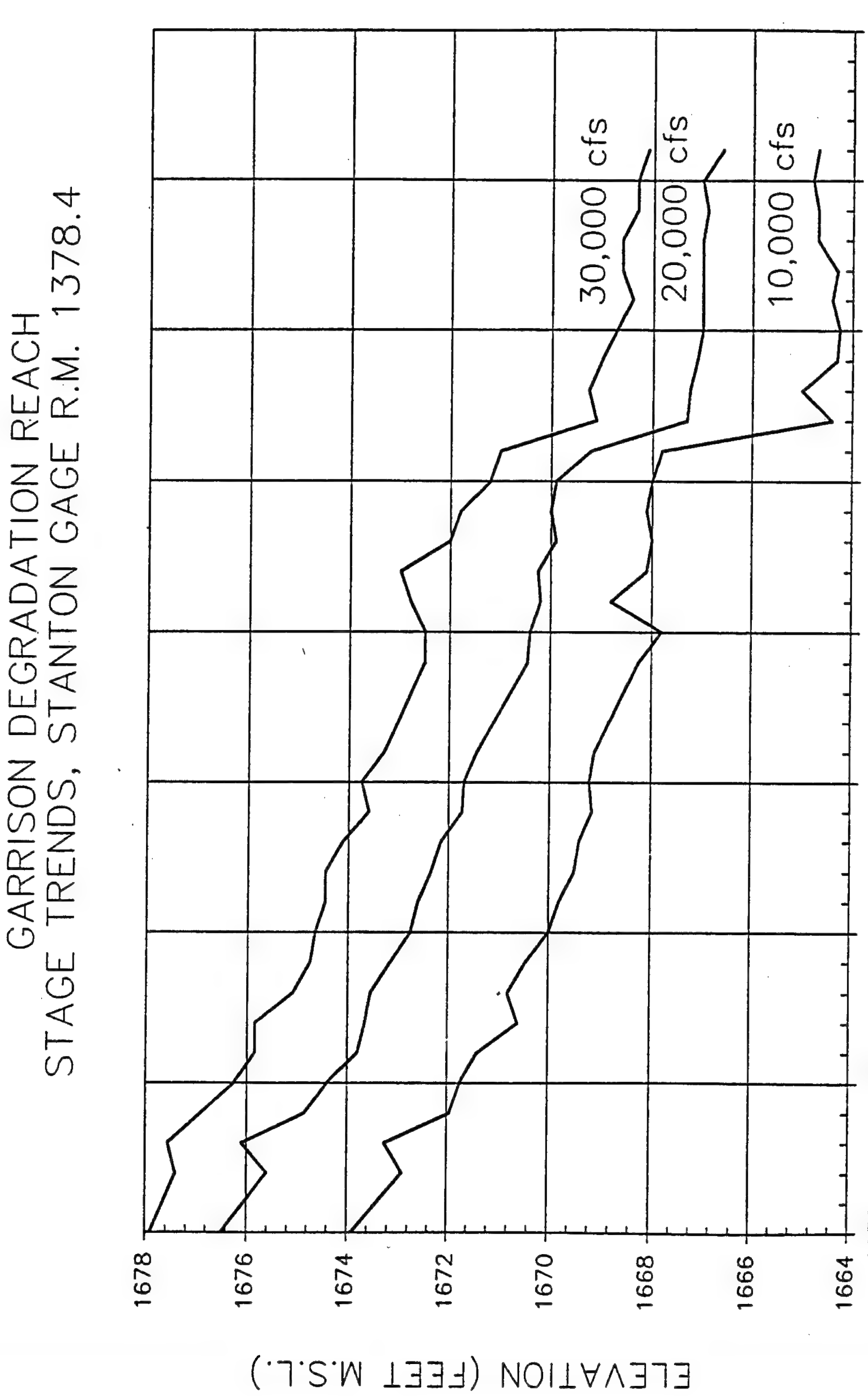

GARRISON AGGRADATION REACH
VOLUME BY SEGMENT (R.M. 1391.12–1456.48)
VOLUME (ACRE-FEET)
1960 RIVER MILE
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0
1380
1390
1400
1410
1420
1430
1440
1450
GARRISON DAM
LITTLE MISSOURI RIVER
1988
1956

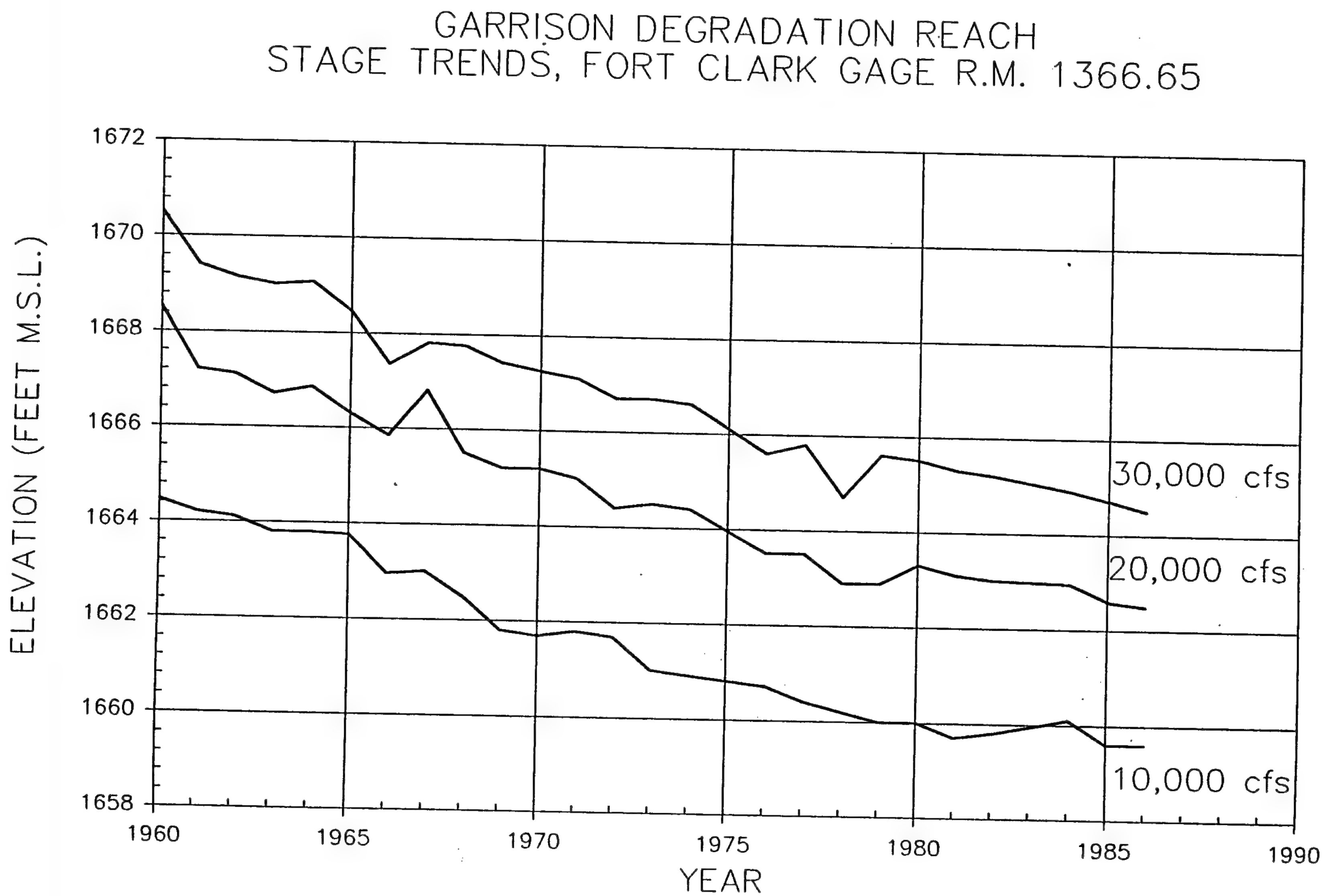
GARRISON AGGRADATION REACH
D50 GRAIN SIZE DISTRIBUTION



MISSOURI RIVER BELOW GARRISON DAM
WATER SURFACE PROFILES
ADJUSTED TO DISCHARGE OF 20,000 C.F.S.

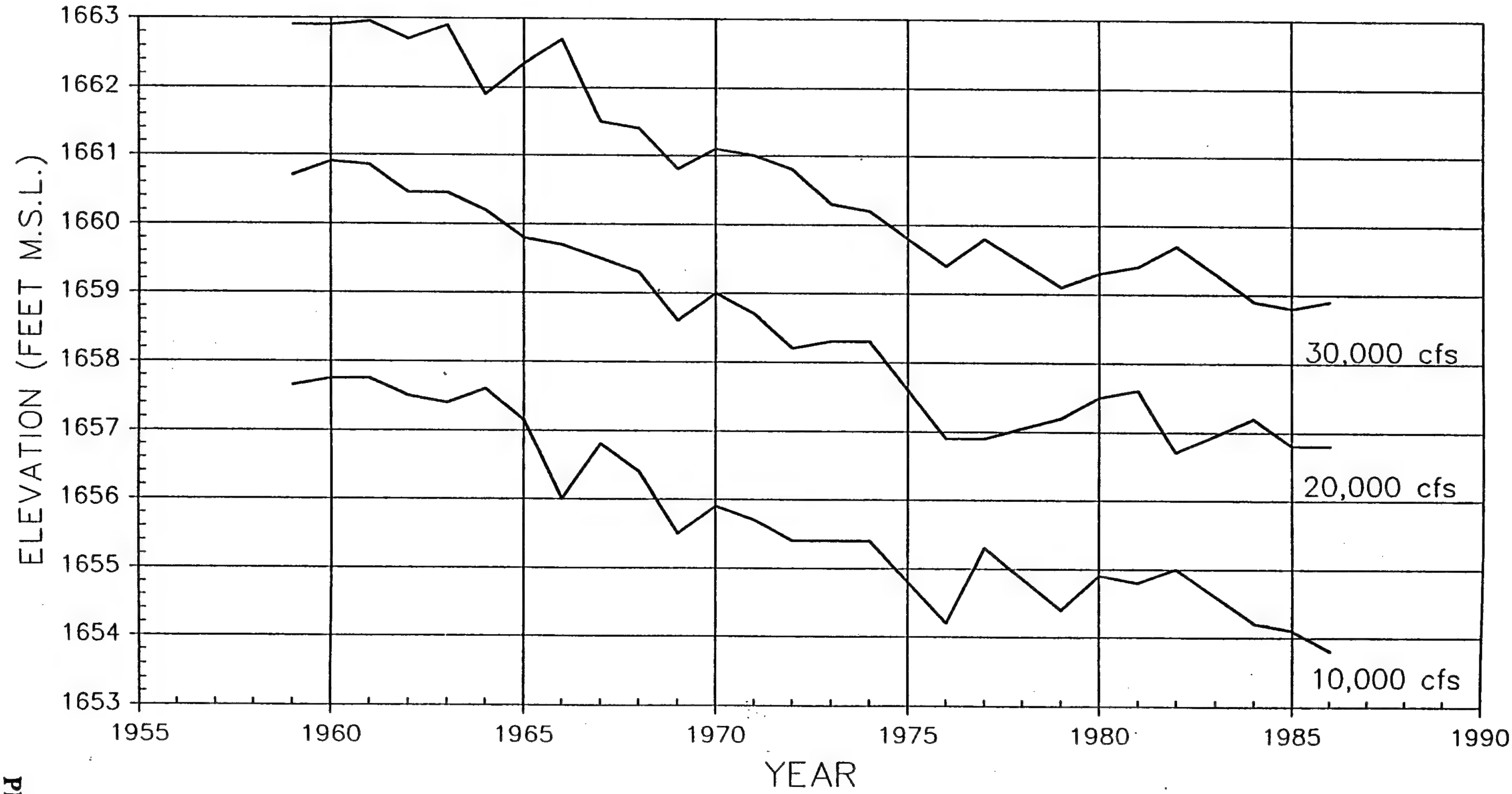


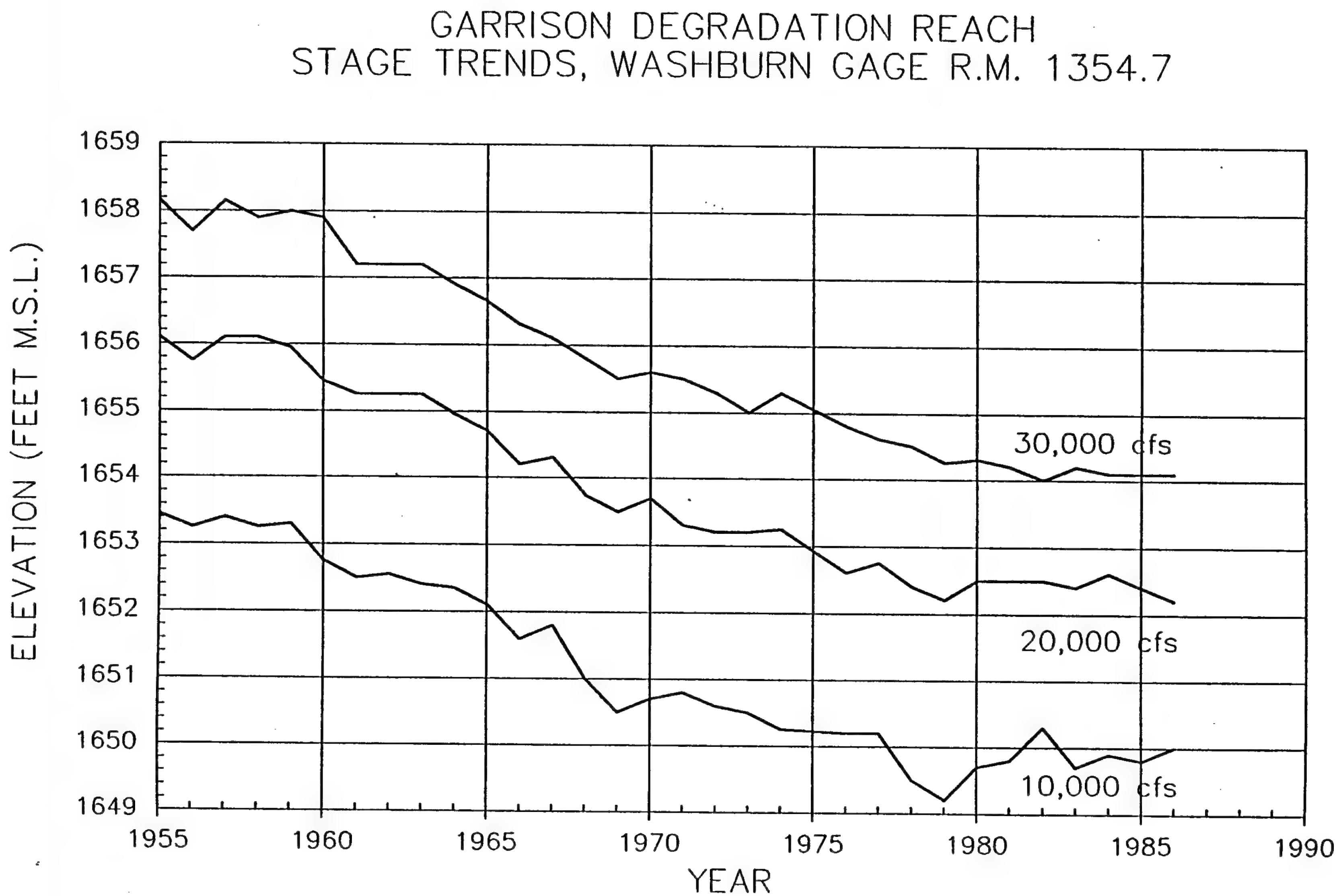

GARRISON DEGRADATION REACH
STAGE TRENDS, STANTON GAGE R.M. 1378.4
30,000 cfs
20,000 cfs
10,000 cfs
ELEVATION (FEET M.S.L.)
1678
1676
1674
1672
1670
1668
1666
1664
YEAR
1950
1955
1960
1965
1970
1975
1980
1985
1990



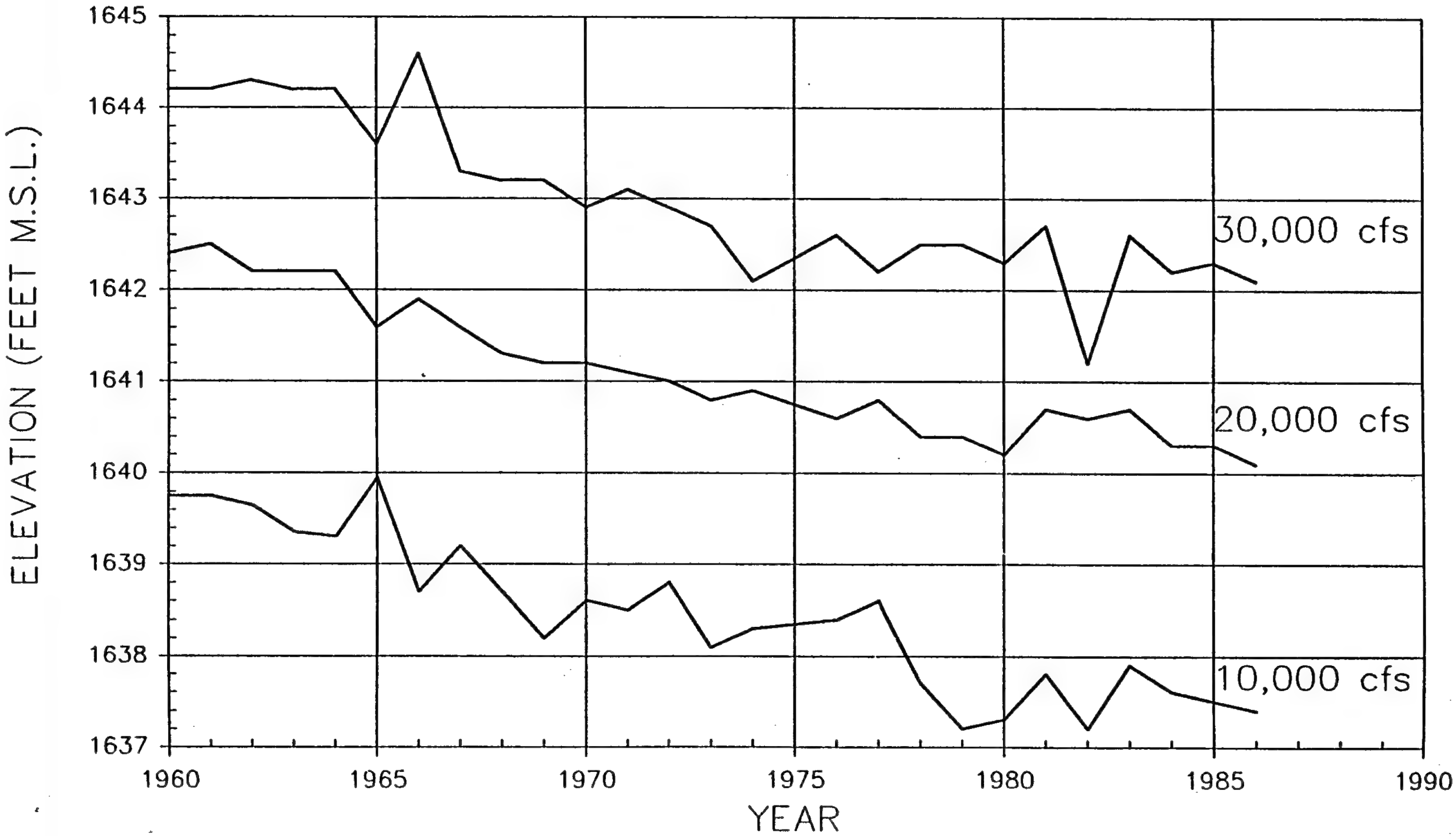
GARRISON DEGRADATION REACH
STAGE TRENDS, FORT CLARK GAGE R.M. 1366.65
ELEVATION (FEET M.S.L.)
1672
1670
1668
1666
1664
1662
1660
1658
1960
1965
1970
1975
1980
1985
1990
YEAR
30,000 cfs
20,000 cfs
10,000 cfs

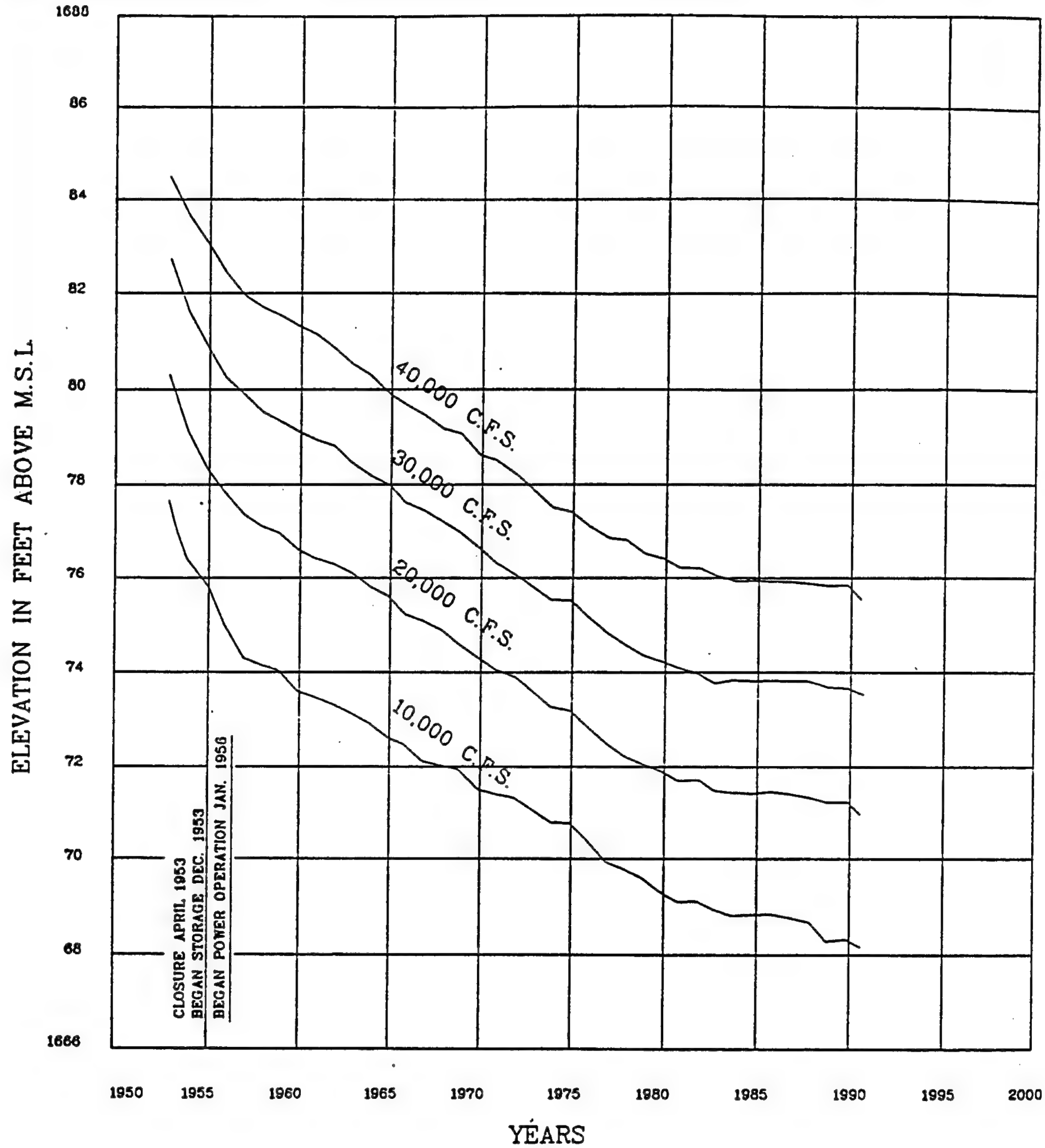
GARRISON DEGRADATION REACH
STAGE TRENDS, HENSLER GAGE R.M. 1362.0



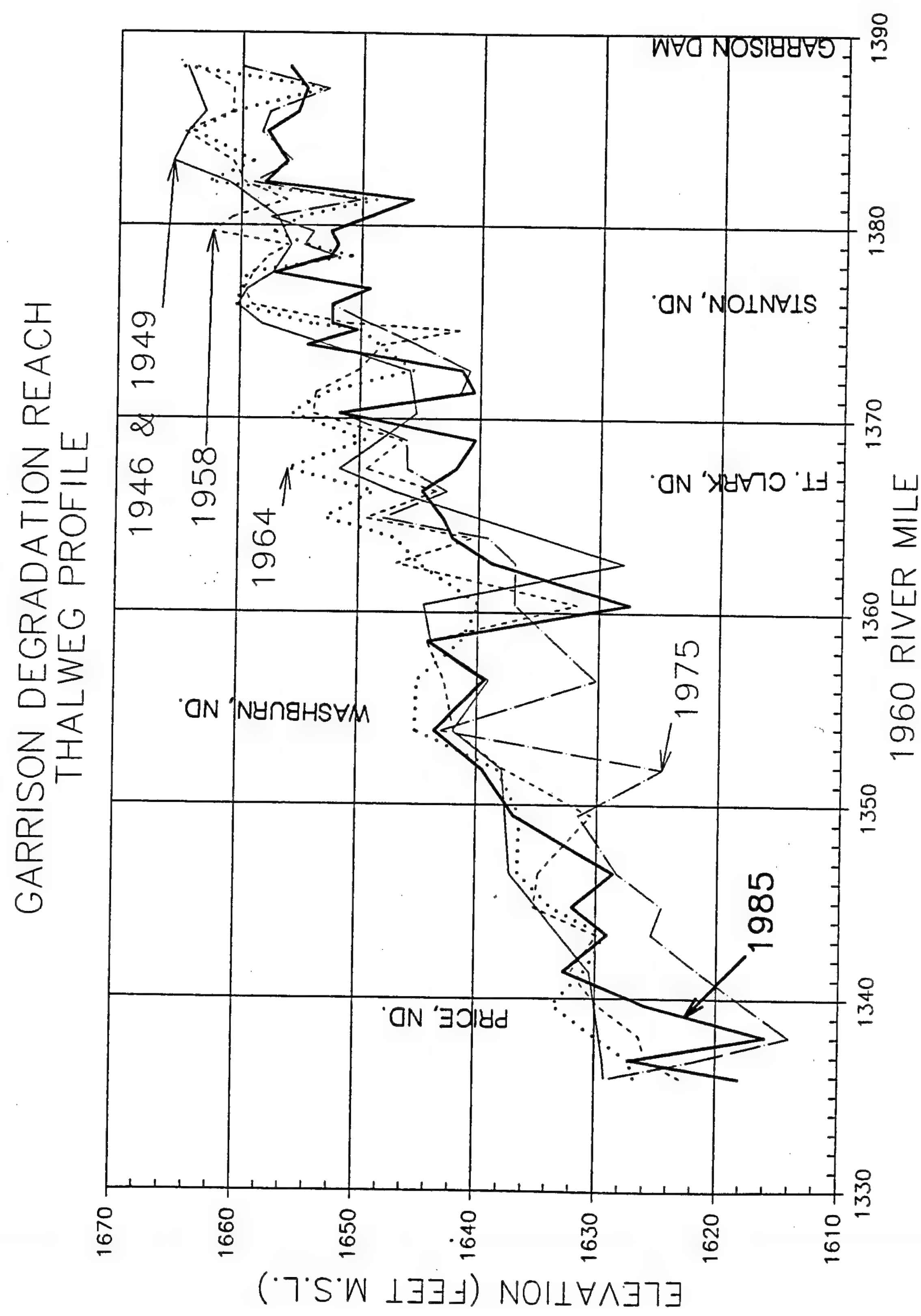

GARRISON DEGRADATION REACH
STAGE TRENDS, WASHBURN GAGE R.M. 1354.7
ELEVATION (FEET M.S.L.)
1659
1658
1657
1656
1655
1654
1653
1652
1651
1650
1649
1955
1960
1965
1970
1975
1980
1985
1990
YEAR
30,000 cfs
20,000 cfs
10,000 cfs

GARRISON DEGRADATION REACH
STAGE TRENDS, PRICE GAGE R.M. 1338.0

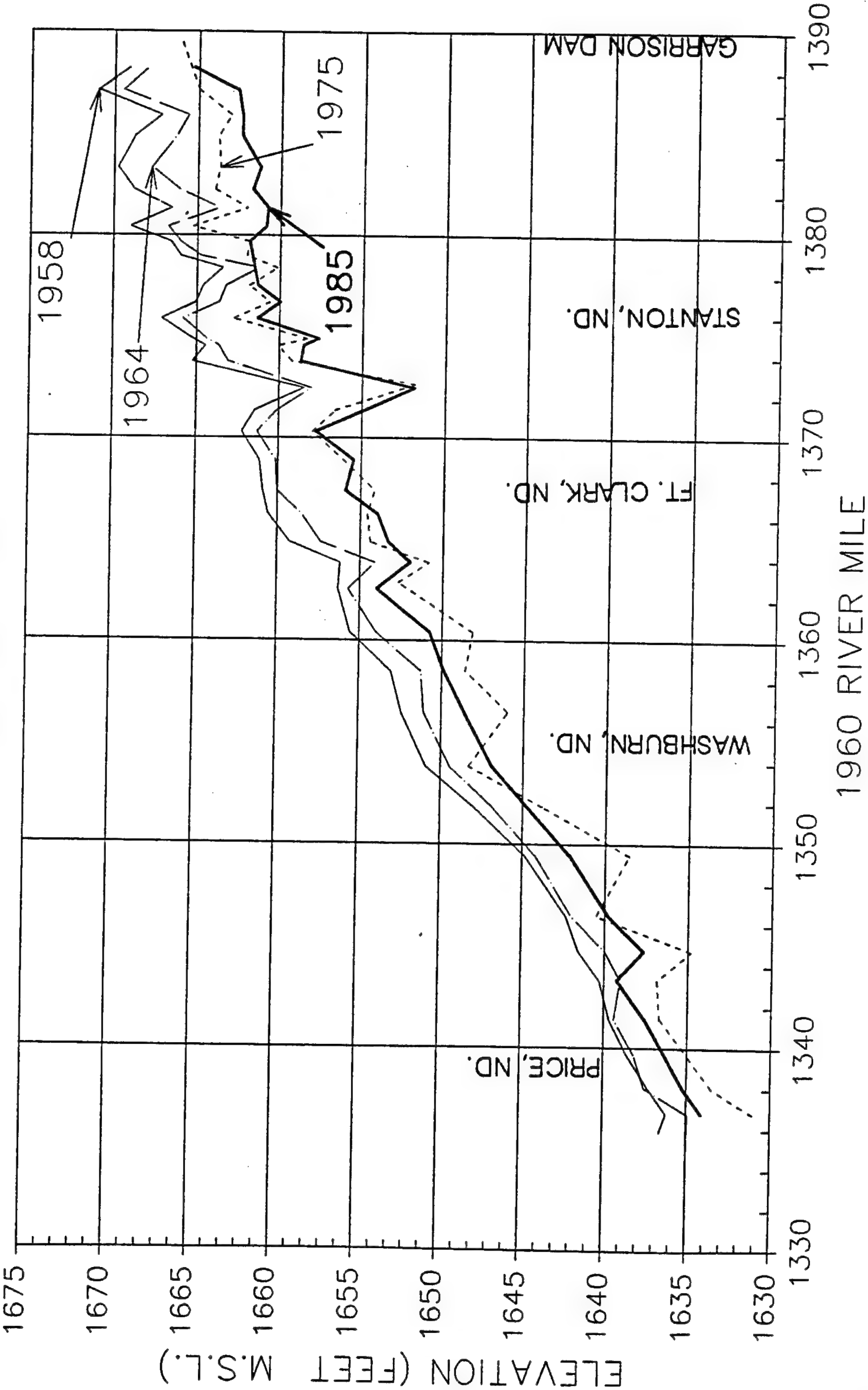


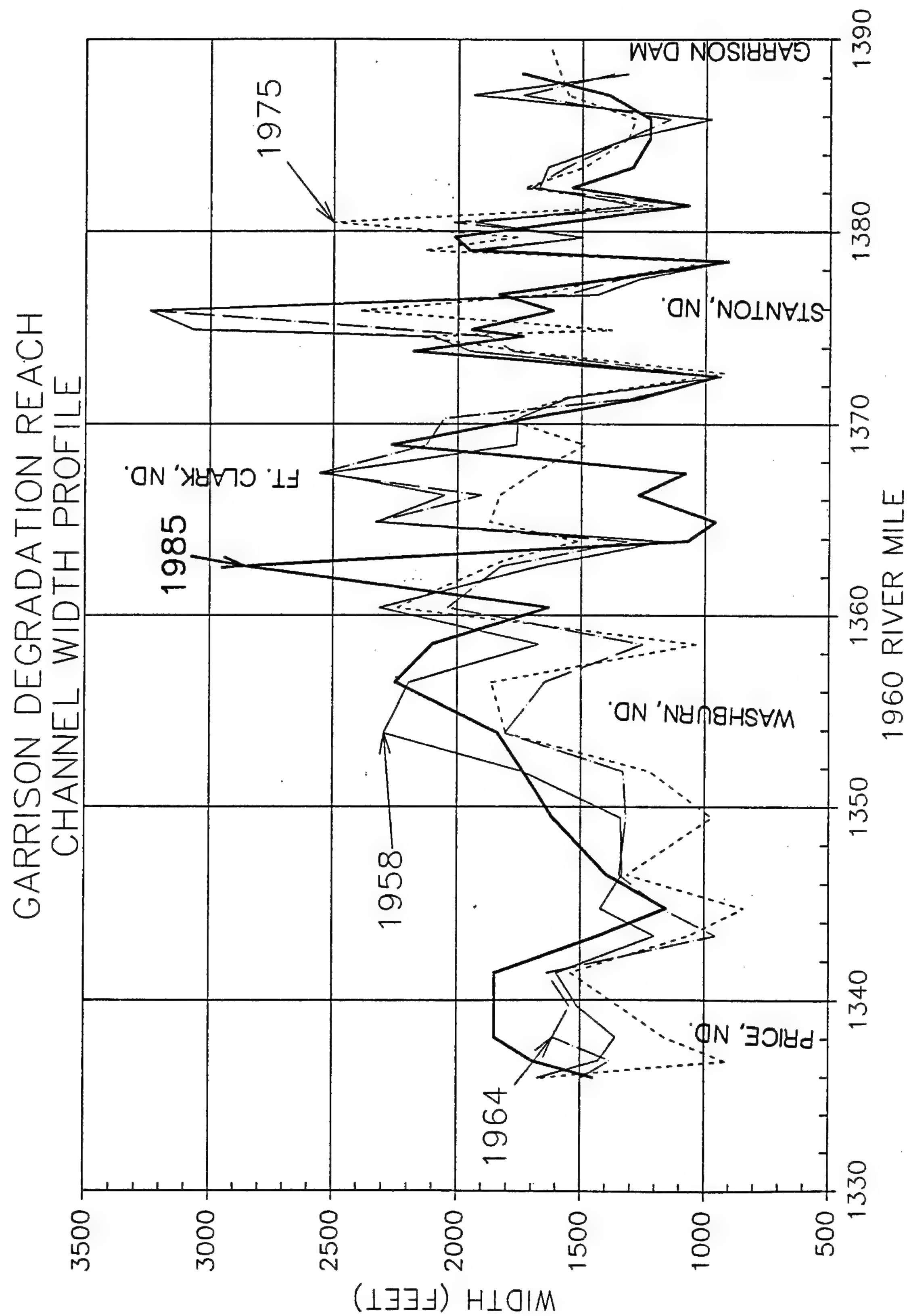


MISSOURI RIVER
GARRISON PROJECT
TAILWATER TRENDS
U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA
MARCH 1992

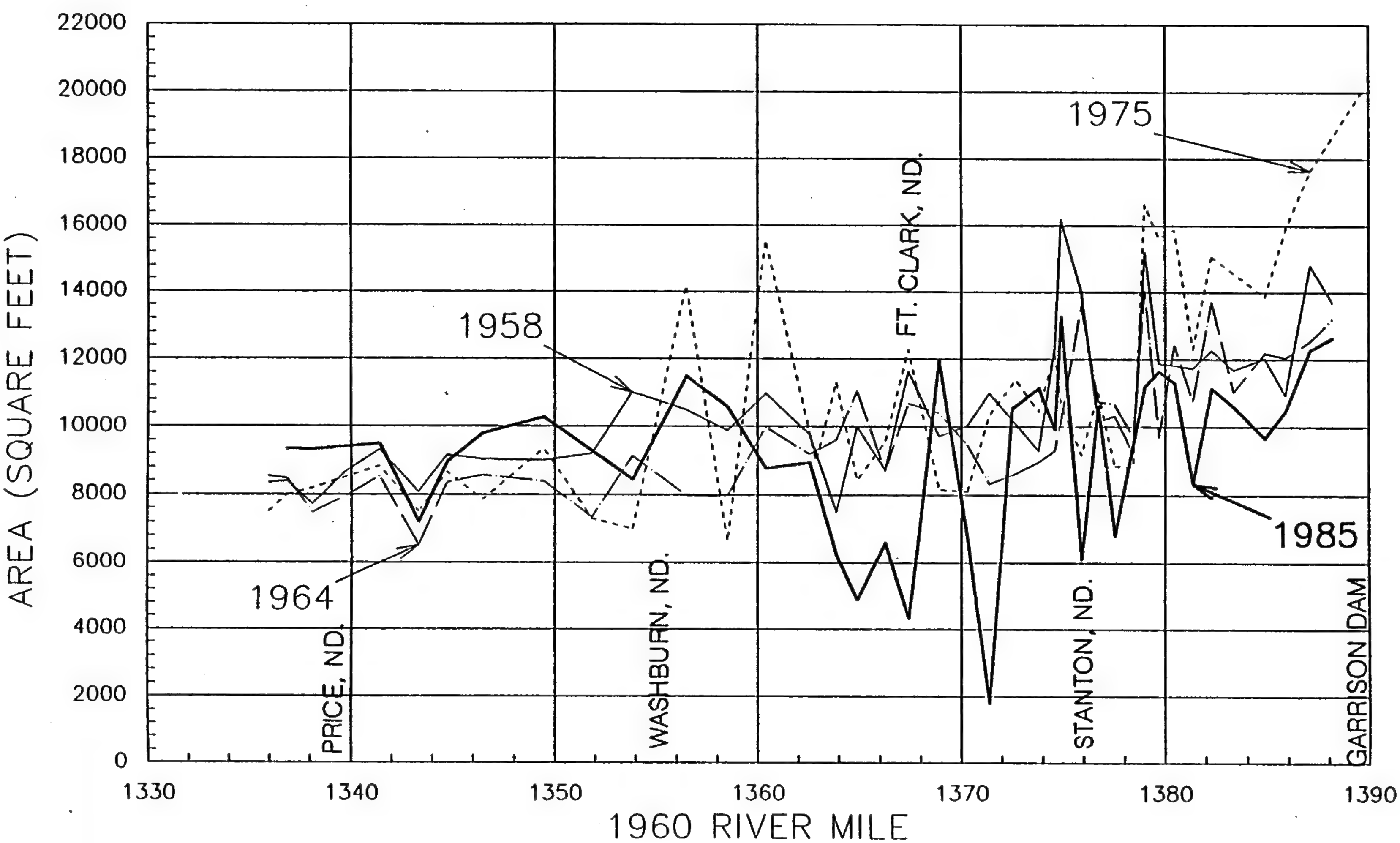

GARRISON DEGRADATION REACH
THALWEG PROFILE
1946 & 1949
1958
1964
1975
1985
GARRISON DAM
STANTON, ND.
FT. CLARK, ND.
WASHBURN, ND.
PRICE, ND.
ELEVATION (FEET M.S.L.)
1670
1660
1650
1640
1630
1620
1610
1960 RIVER MILE
1330
1340
1350
1360
1370
1380
1390

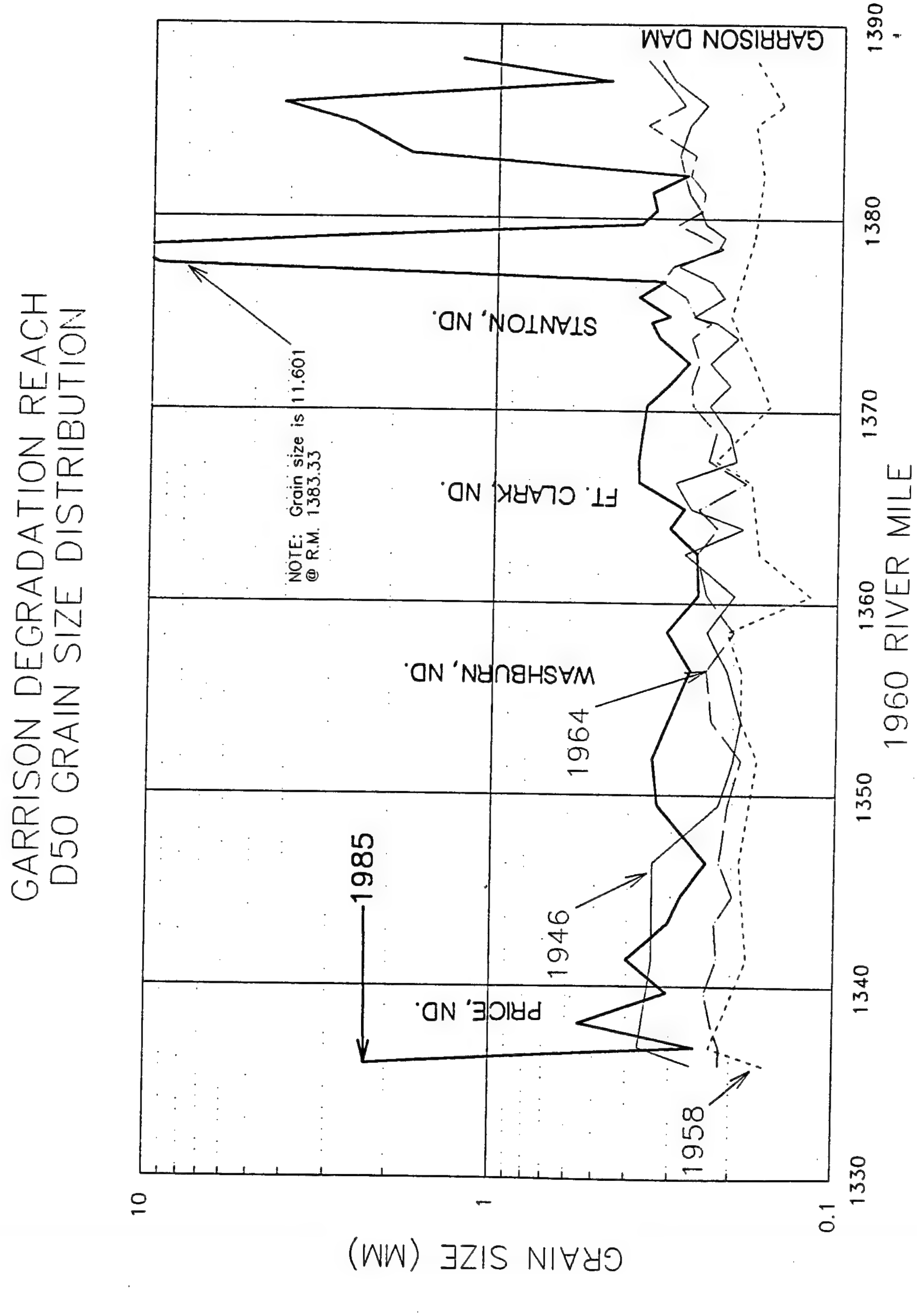
GARRISON DEGRADATION REACH
AVERAGE BED PROFILE



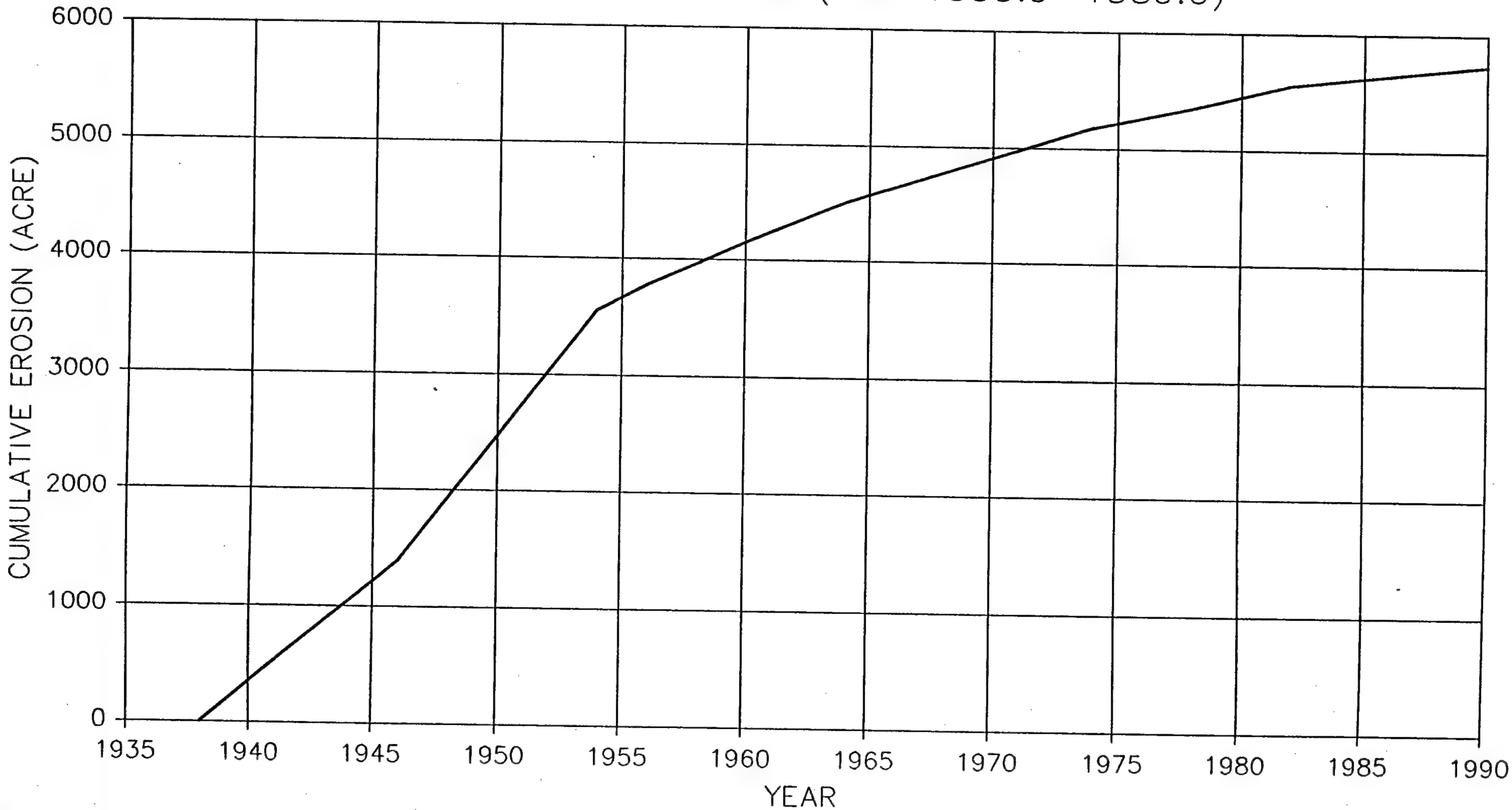

GARRISON DEGRADATION REACH
CHANNEL WIDTH PROFILE
WIDTH (FEET)
3500
3000
2500
2000
1500
1000
500
1960 RIVER MILE
1330
1340
1350
1360
1370
1380
1390
PRICE, ND.
WASHBURN, ND.
FT. CLARK, ND.
STANTON, ND.
GARRISON DAM
1964
1958
1985
1975

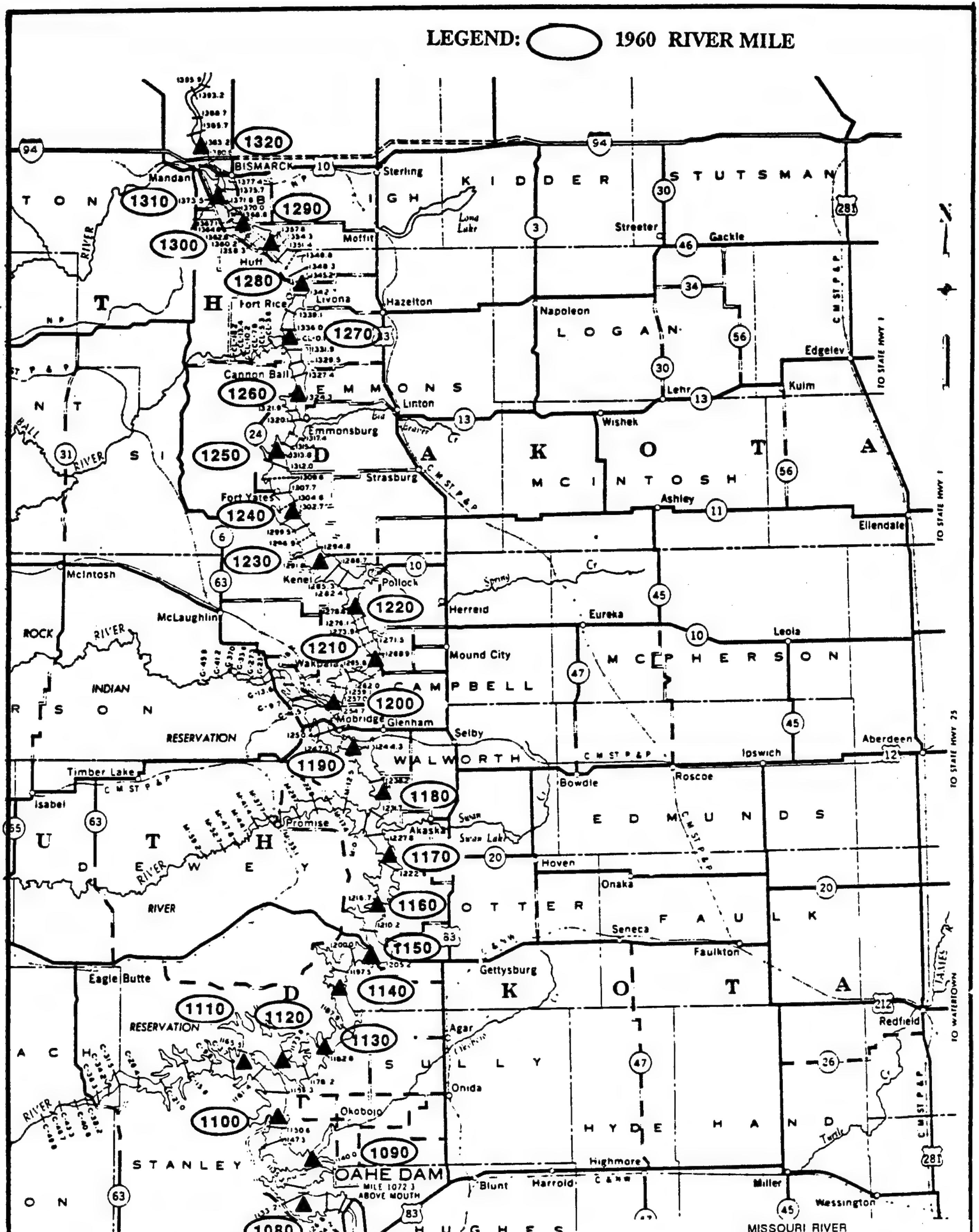
GARRISON DEGRADATION REACH
CHANNEL CROSS-SECTION AREA PROFILE




GARRISON DEGRADATION REACH
D50 GRAIN SIZE DISTRIBUTION
GRAIN SIZE (MM)
1960 RIVER MILE
10
1
0.1
1330
1340
1350
1360
1370
1380
1390
GARRISON DAM
STANTON, ND.
FT. CLARK, ND.
WASHBURN, ND.
PRICE, ND.
NOTE: Grain size is 11.601
@ R.M. 1383.33
1985
1964
1946
1958

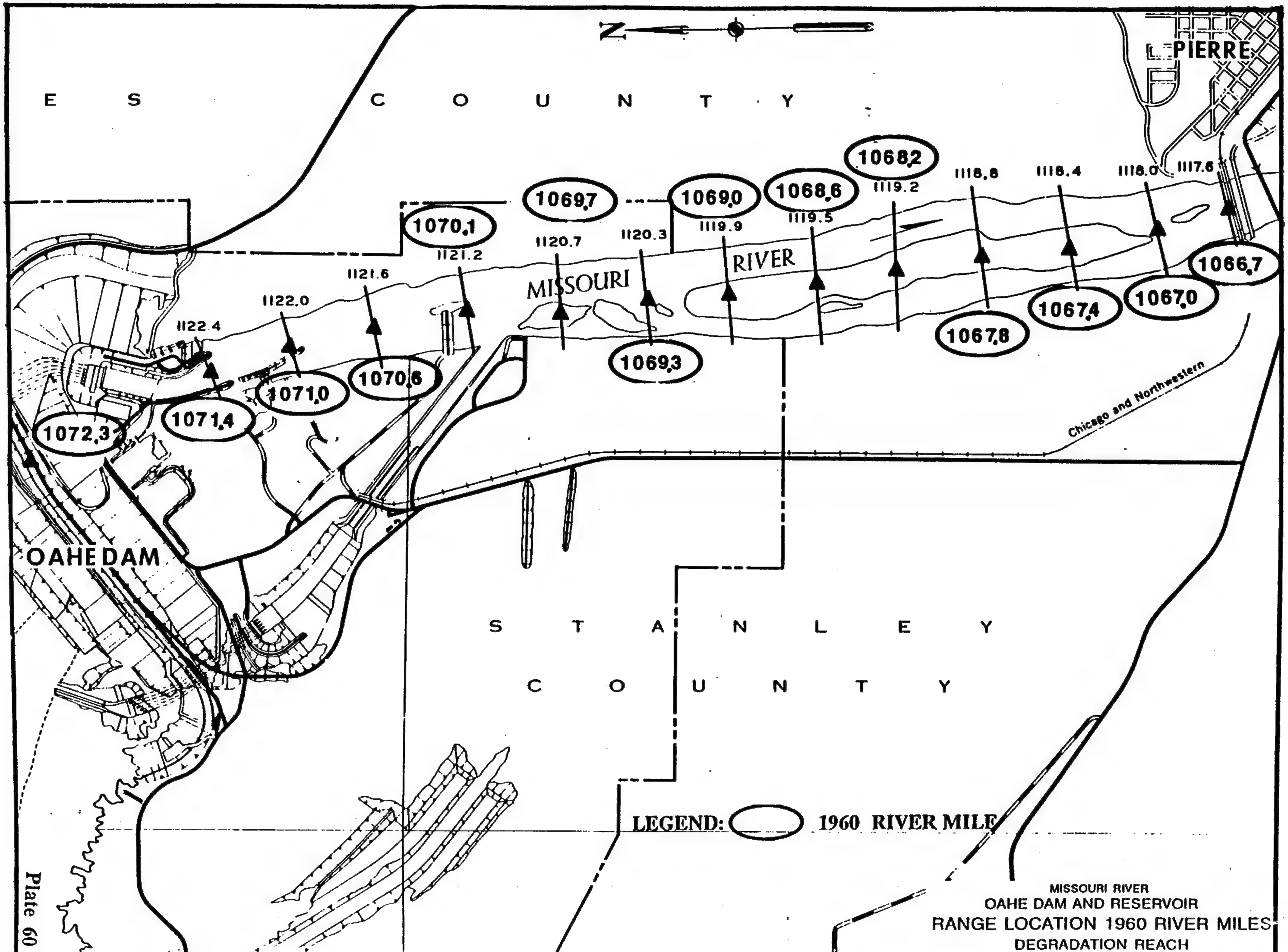
GARRISON DEGRADATION REACH
CUMULATIVE EROSION (R.M. 1335.9–1389.0)





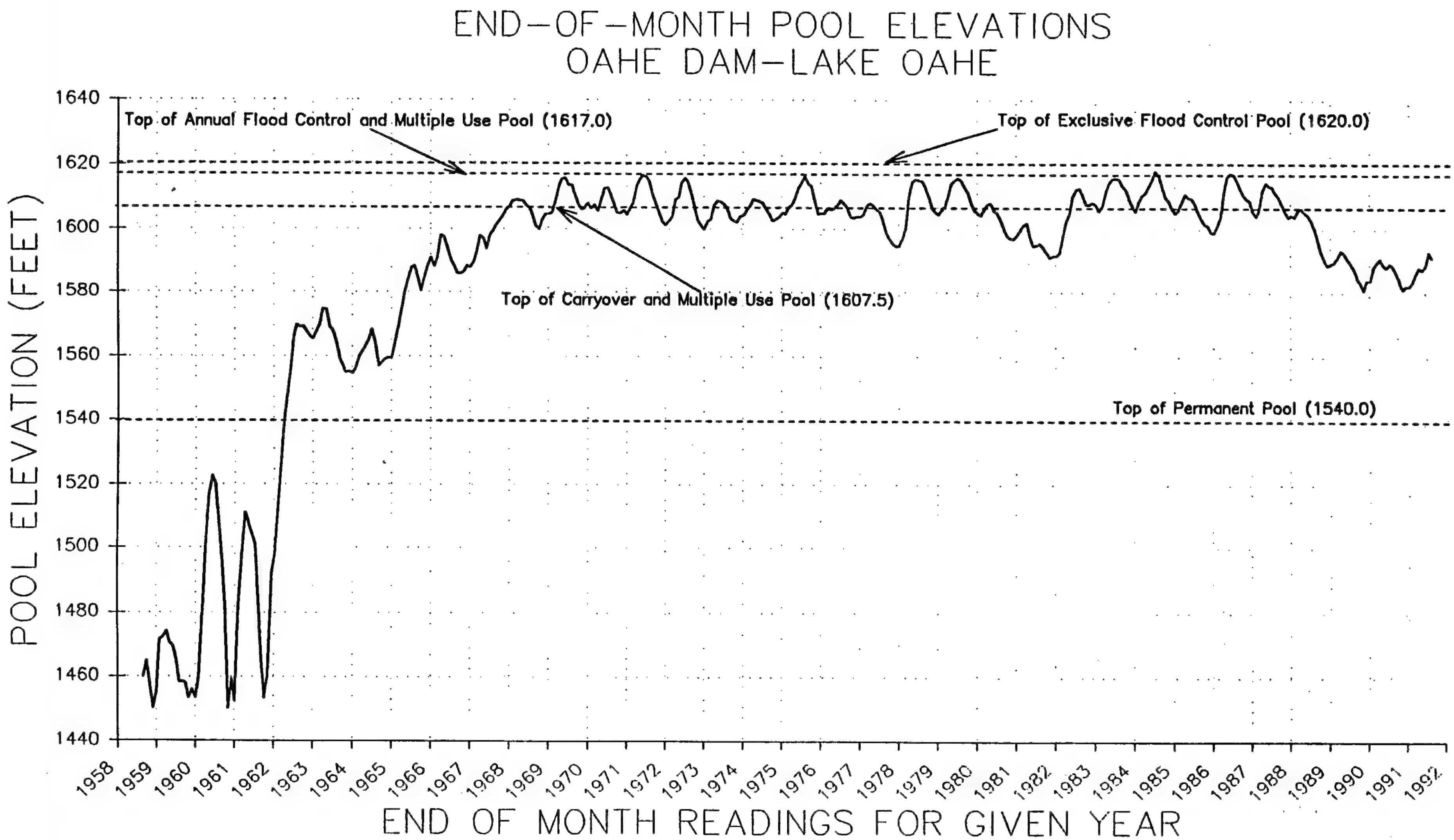
MISSOURI RIVER
OAHE DAM AND RESERVOIR
RANGE LOCATION 1960 RIVER MILES
AGGRADATION REACH

Plate 59



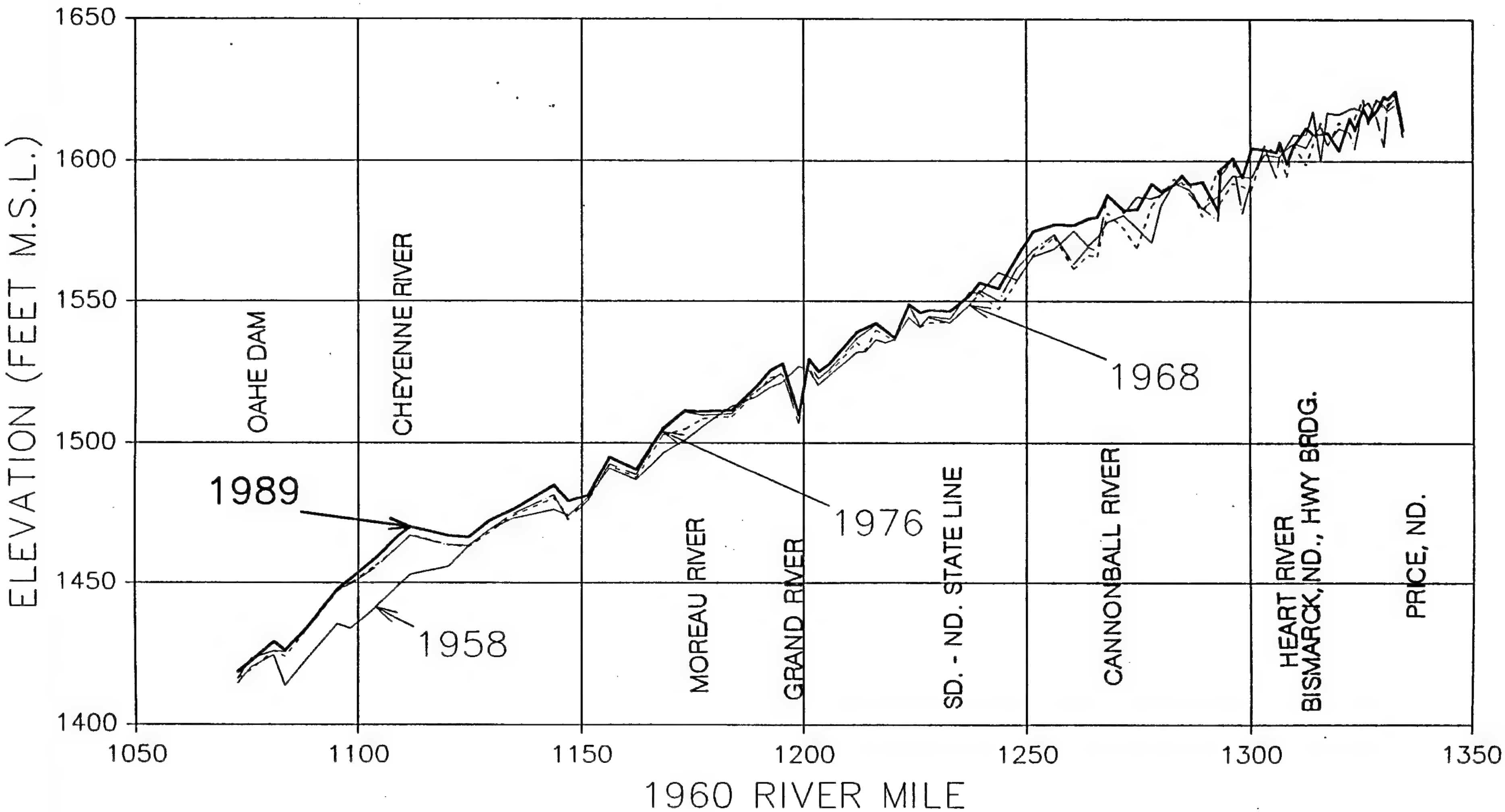
MISSOURI RIVER
OAHE DAM AND RESERVOIR
RANGE LOCATION 1960 RIVER MILES
DEGRADATION REACH

Plate 60

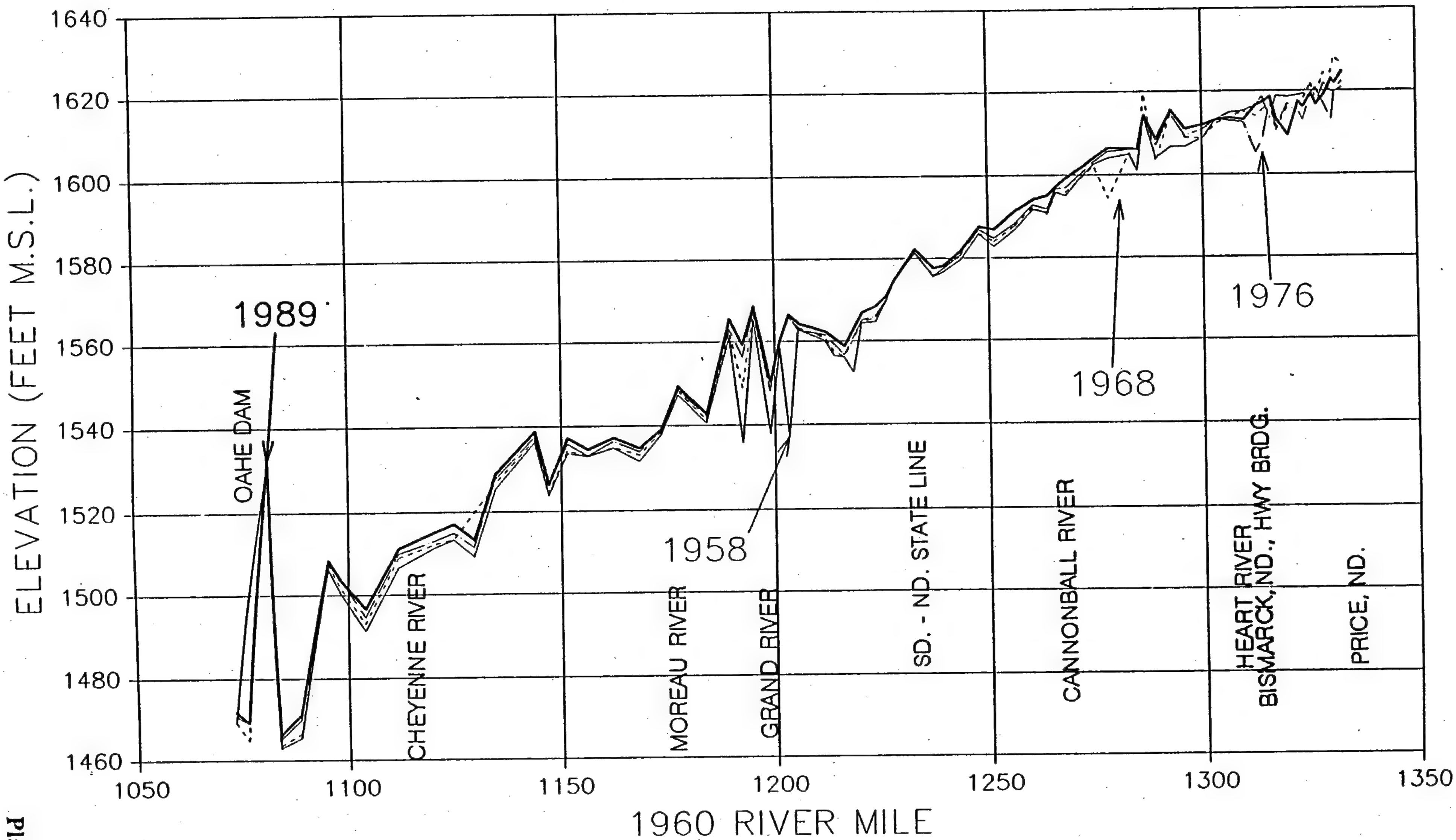


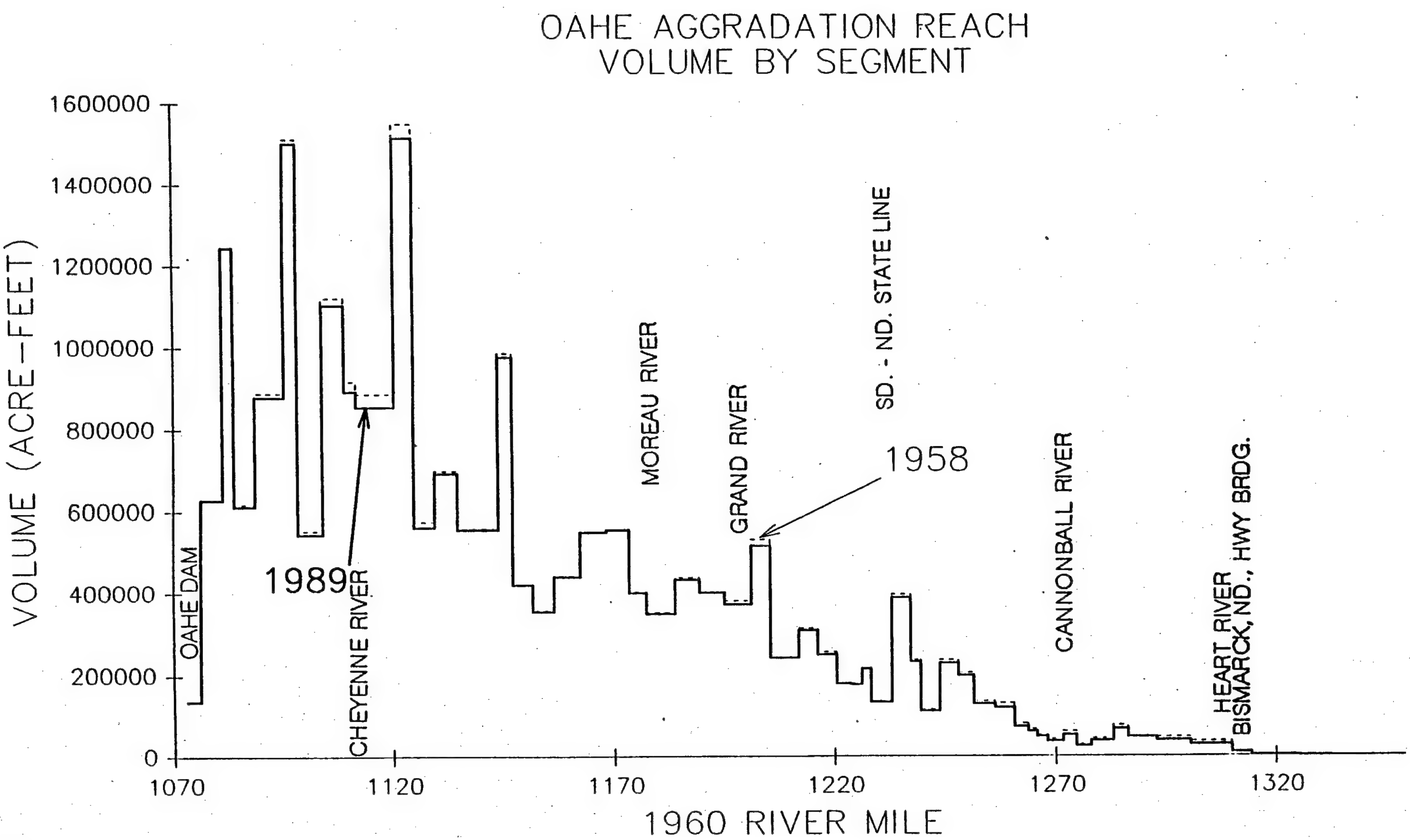
END-OF-MONTH POOL ELEVATIONS
OAHE DAM-LAKE OAHE
Top of Annual Flood Control and Multiple Use Pool (1617.0)
Top of Exclusive Flood Control Pool (1620.0)
Top of Carryover and Multiple Use Pool (1607.5)
Top of Permanent Pool (1540.0)
POOL ELEVATION (FEET)
1640
1620
1600
1580
1560
1540
1520
1500
1480
1460
1440
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
END OF MONTH READINGS FOR GIVEN YEAR

OAHE AGGRADATION REACH
THALWEG PROFILE

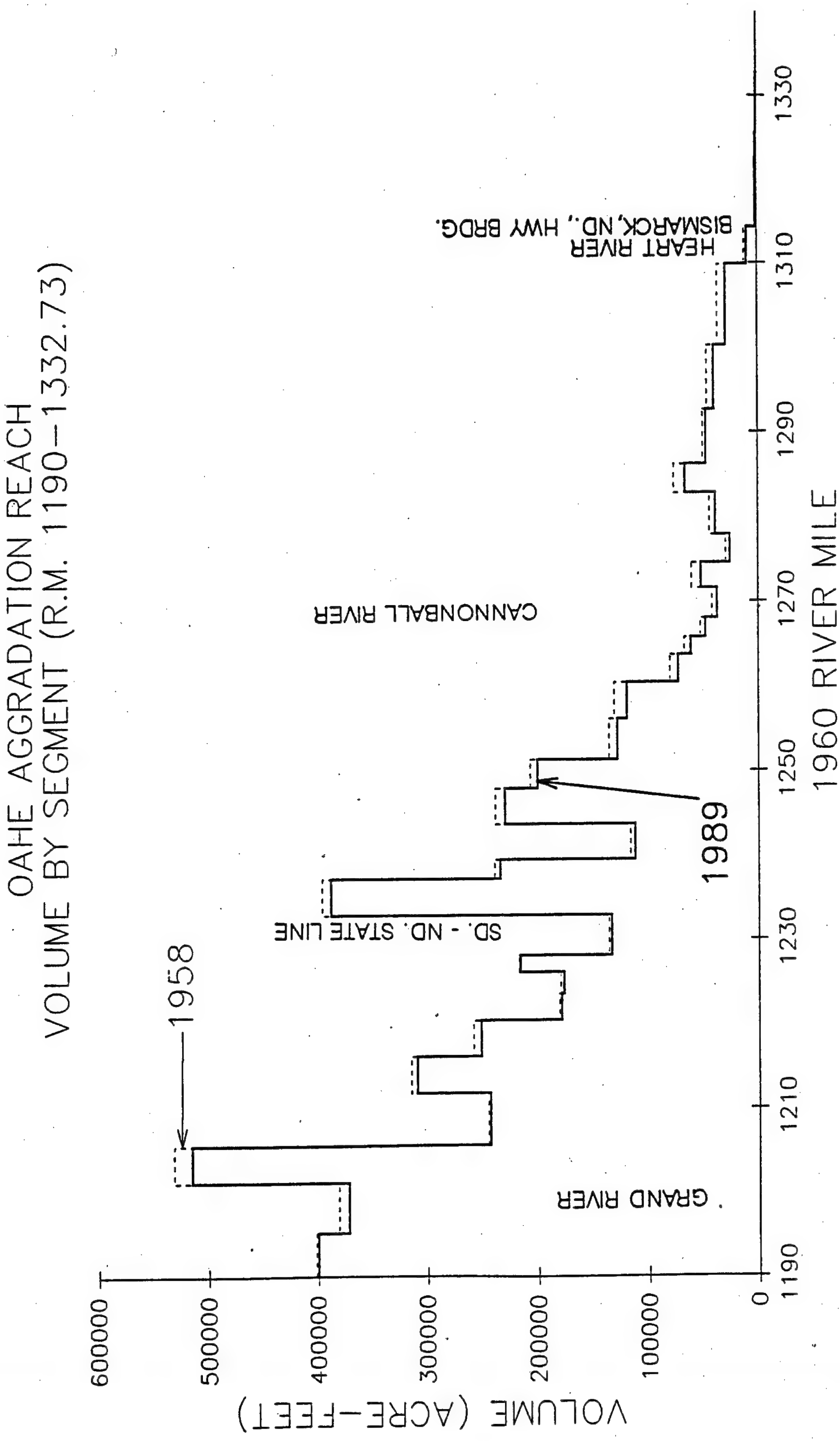


OAHE AGGRADATION REACH
AVERAGE BED PROFILE



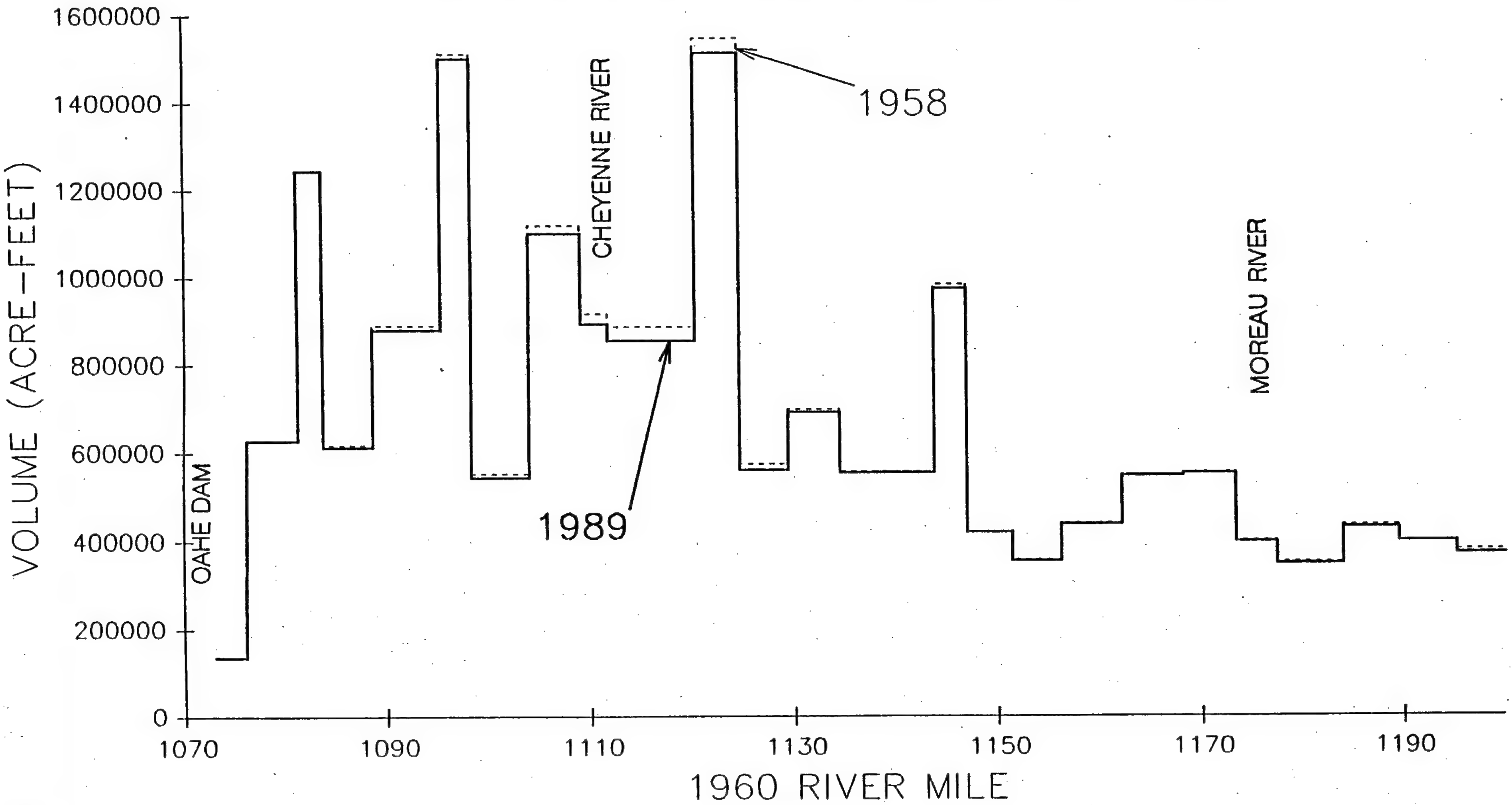


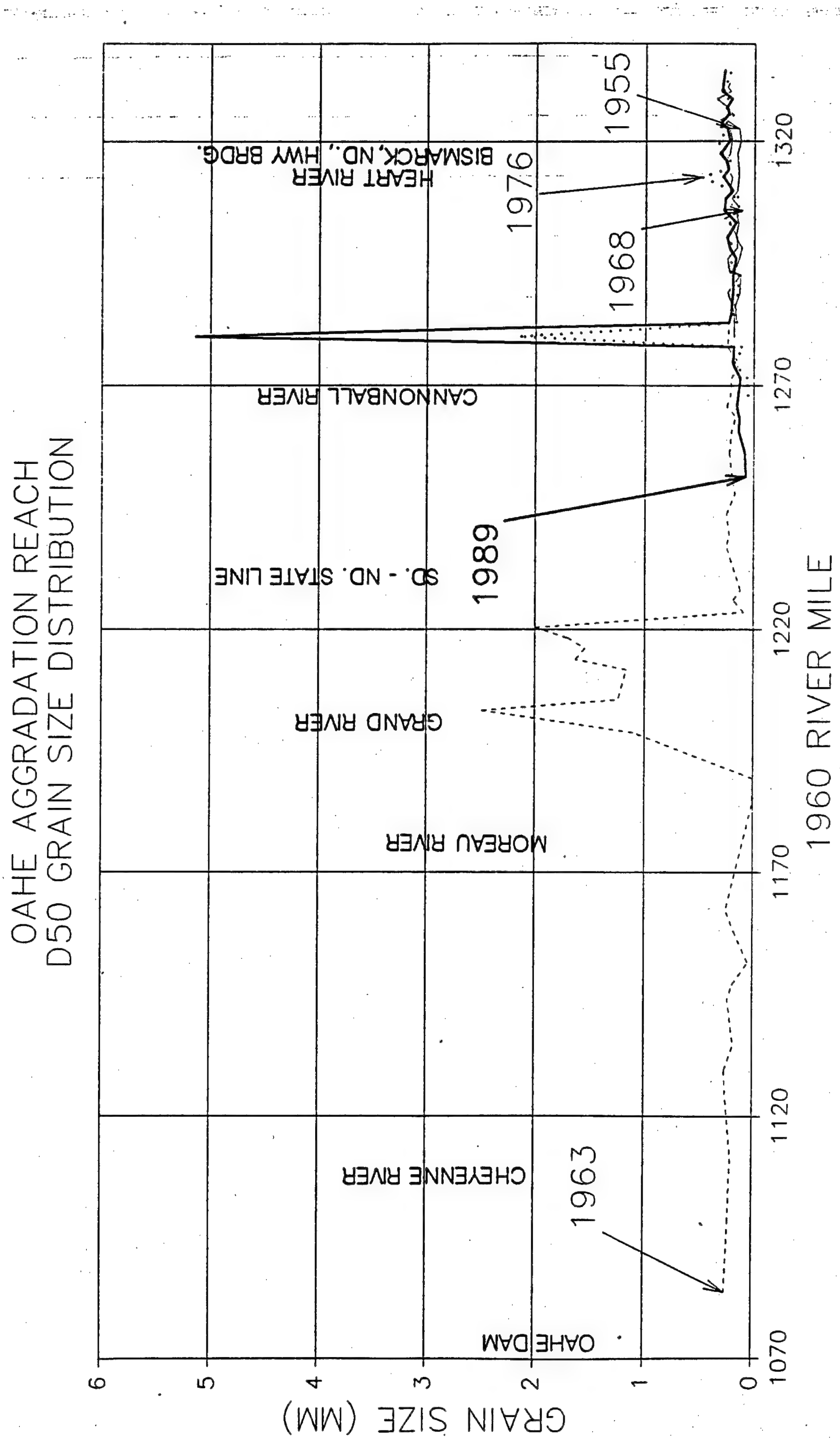
OAHE AGGRADATION REACH
VOLUME BY SEGMENT
VOLUME (ACRE-FEET)
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0
1070
1120
1170
1220
1270
1320
1960 RIVER MILE
OAHE DAM
CHEYENNE RIVER
1989
MOREAU RIVER
GRAND RIVER
SD. - ND. STATE LINE
1958
CANNONBALL RIVER
HEART RIVER
BISMARCK, ND., HWY BRDG.



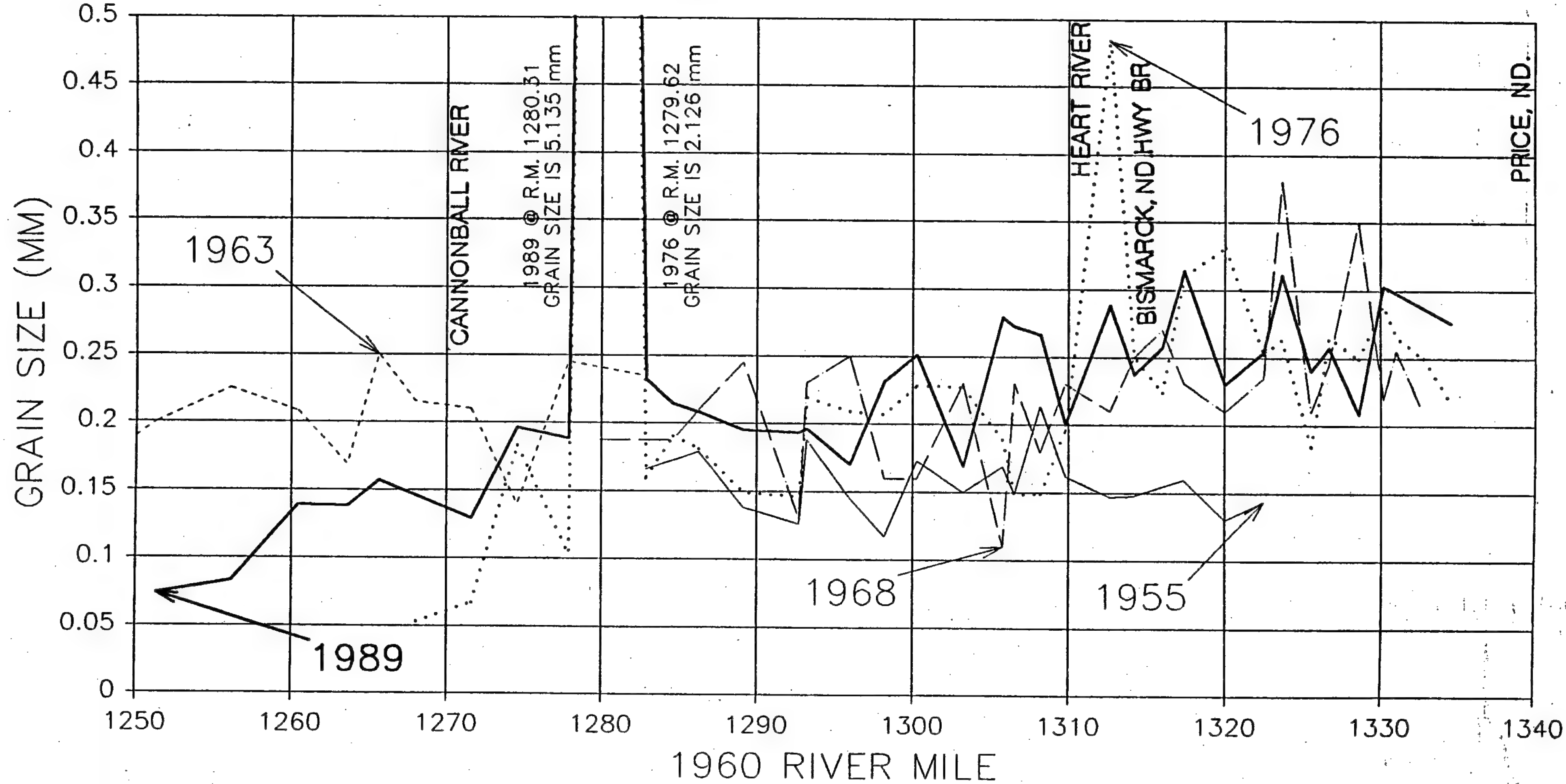
OAHE AGGRADATION REACH
VOLUME BY SEGMENT (R.M. 1190–1332.73)
VOLUME (ACRE-FEET)
1960 RIVER MILE
0
100000
200000
300000
400000
500000
600000
1190
1210
1230
1250
1270
1290
1310
1330
1958
1989
GRAND RIVER
SD. - ND. STATE LINE
CANNONBALL RIVER
HEART RIVER
BISMARCK, ND., HWY BRDG.

OAHE AGGRADATION REACH
VOLUME BY SEGMENT (R.M. 1073.07-1200)

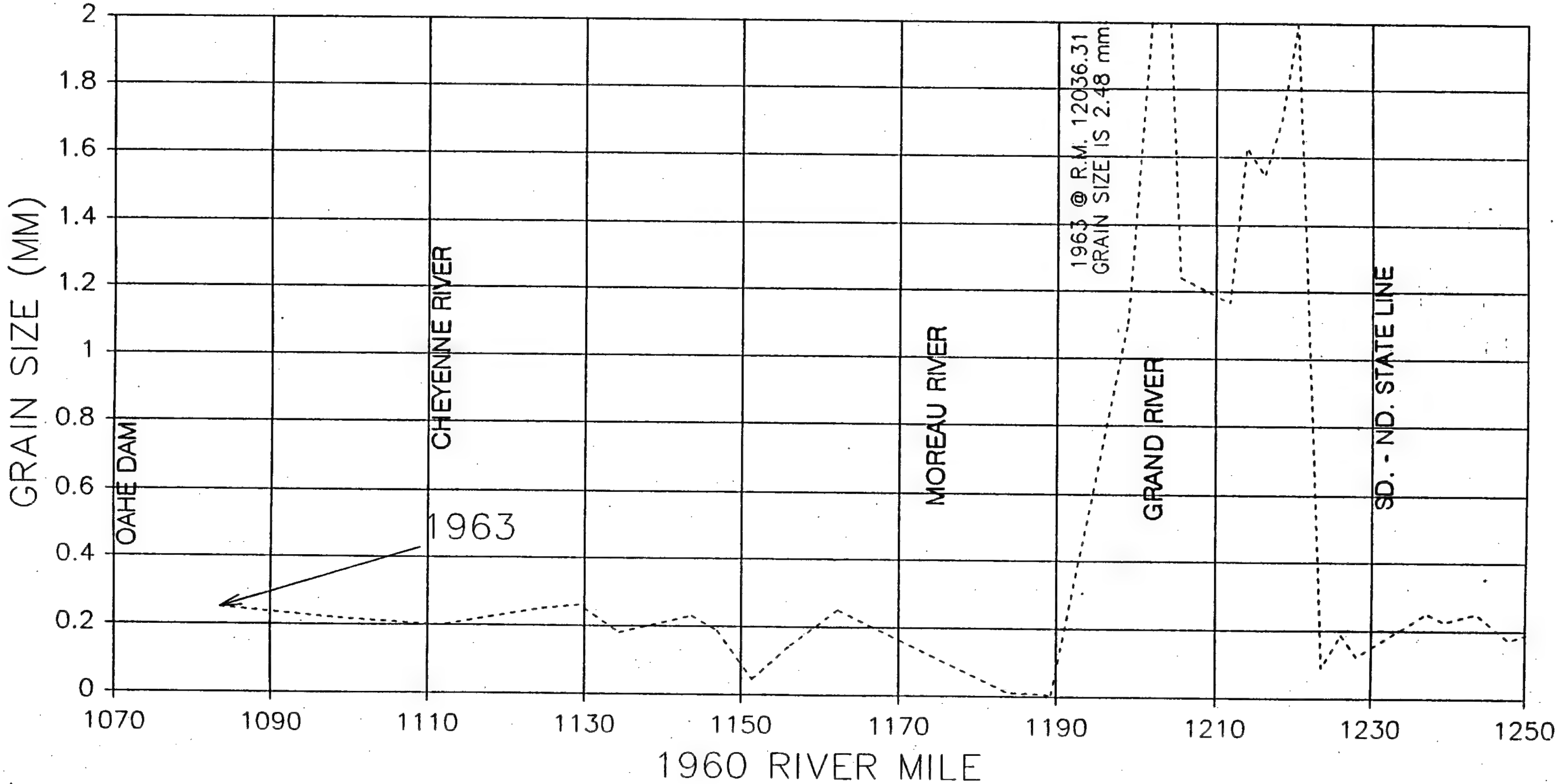


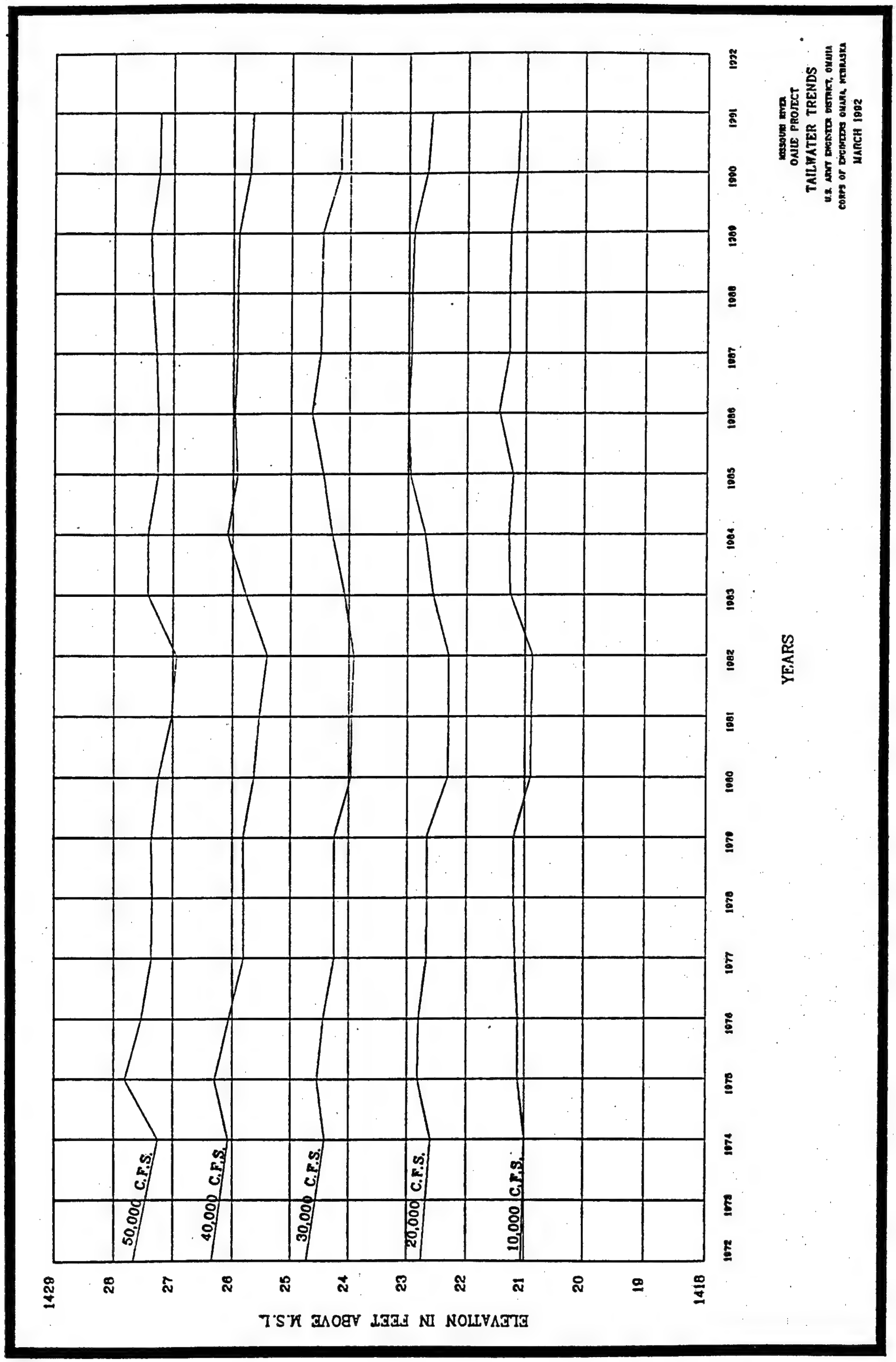

OAHE AGGRADATION REACH
D50 GRAIN SIZE DISTRIBUTION
GRAIN SIZE (MM)
1960 RIVER MILE
0
1
2
3
4
5
6
1070
1120
1170
1220
1270
1320
OAHE DAM
CHEYENNE RIVER
MOREAU RIVER
GRAND RIVER
SD. - ND. STATE LINE
CANNONBALL RIVER
HEART RIVER
BISMARCK, ND., HWY BRDG.
1963
1989
1968
1976
1955

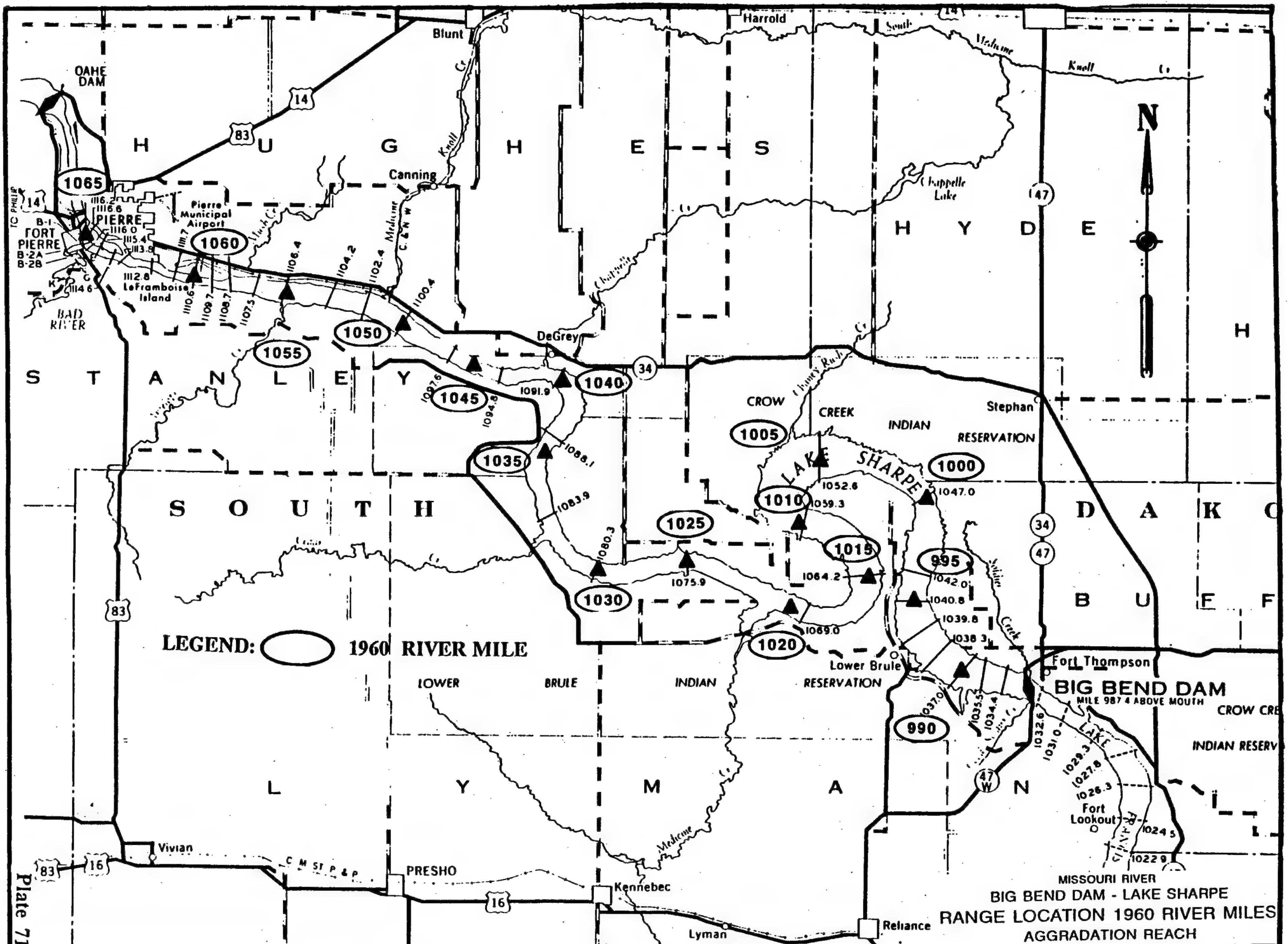
OAHE AGGRADATION REACH
D50 GRAIN SIZE DISTRIBUTION
(RM 1250–1334.5)



OAHE AGGRADATION REACH
D50 GRAIN SIZE DISTRIBUTION
(RM 1083.63–1250)



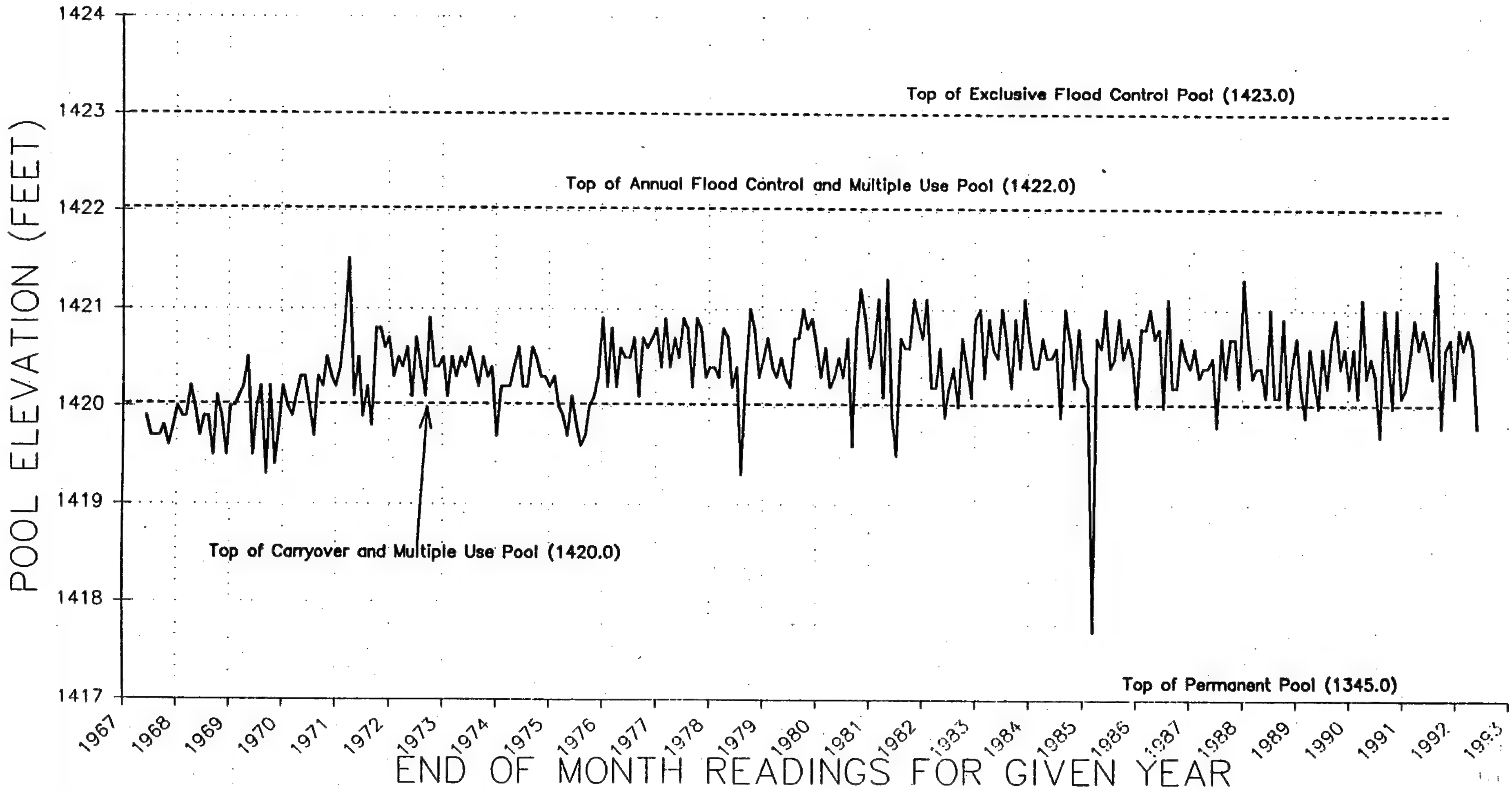

MISSOURI RIVER
OAHE PROJECT
TAILWATER TRENDS
U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA
MARCH 1992
YEARS
ELEVATION IN FEET ABOVE M.S.L.
50,000 C.F.S.
40,000 C.F.S.
30,000 C.F.S.
20,000 C.F.S.
10,000 C.F.S.
1429
28
27
26
25
24
23
22
21
20
19
1418
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992



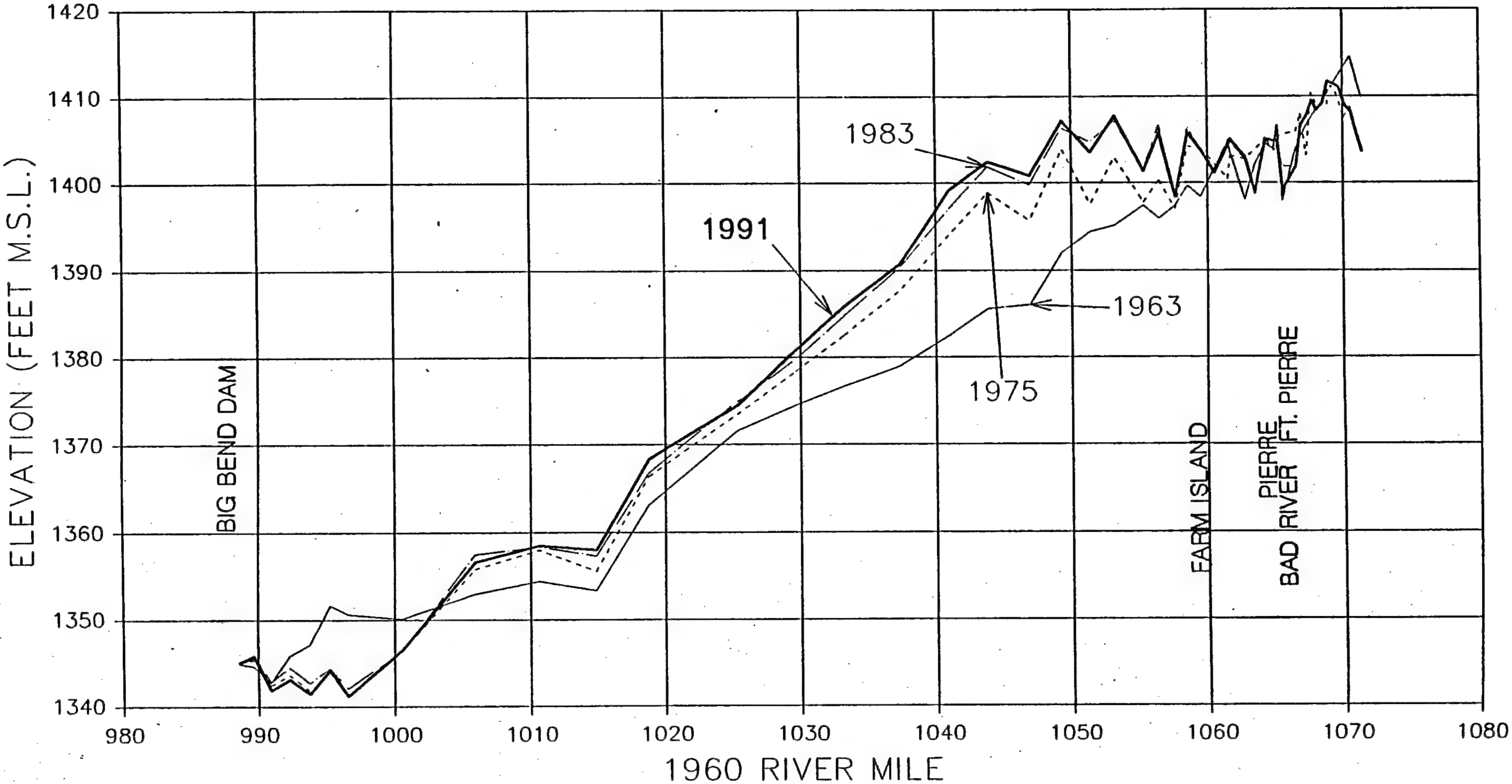
OAHE DAM
PIERRE
FORT PIERRE
BAD RIVER
LaFramboise Island
Pierre Municipal Airport
Canning
Blunt
Harrold
DeGrey
Stephan
Fort Thompson
Lower Brule
Fort Lookout
Vivian
PRESHO
Kennebec
Lyman
Reliance
H U G H E S
HYDE
STANLEY
SOUTH DAKOTA
BUFFALO
LYMAN
CROW CREEK INDIAN RESERVATION
LOWER BRULE INDIAN RESERVATION
LAKE SHARPE
LAKE FRANCIS
BIG BEND DAM
MILE 987.4 ABOVE MOUTH
LEGEND:
1960 RIVER MILE
1065
1060
1055
1050
1045
1040
1035
1030
1025
1020
1015
1010
1005
1000
995
990
N
MISSOURI RIVER
BIG BEND DAM - LAKE SHARPE
RANGE LOCATION 1960 RIVER MILES
AGGRADATION REACH

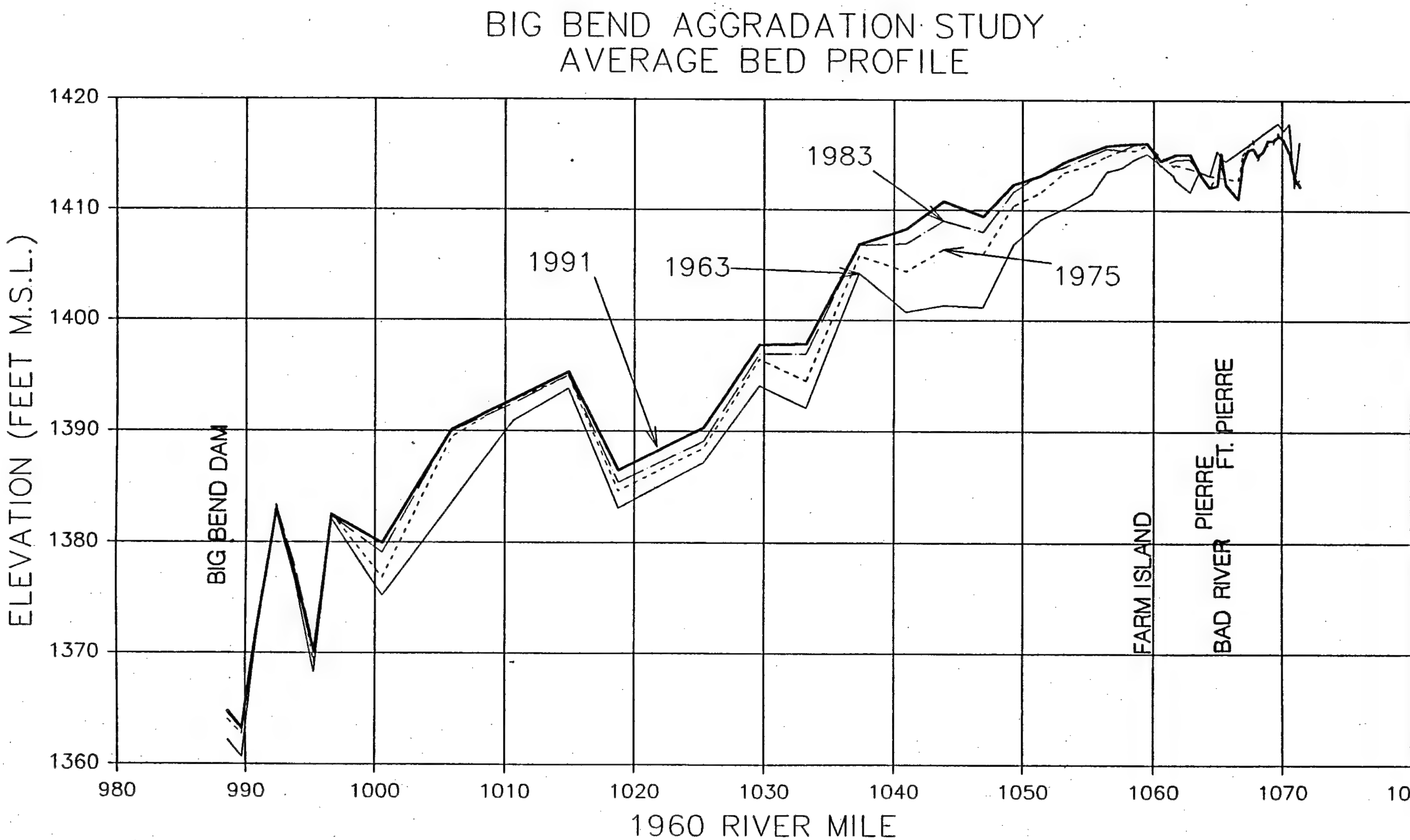
Plate 71

END-OF-MONTH POOL ELEVATIONS
BIG BEND DAM-LAKE SHARPE

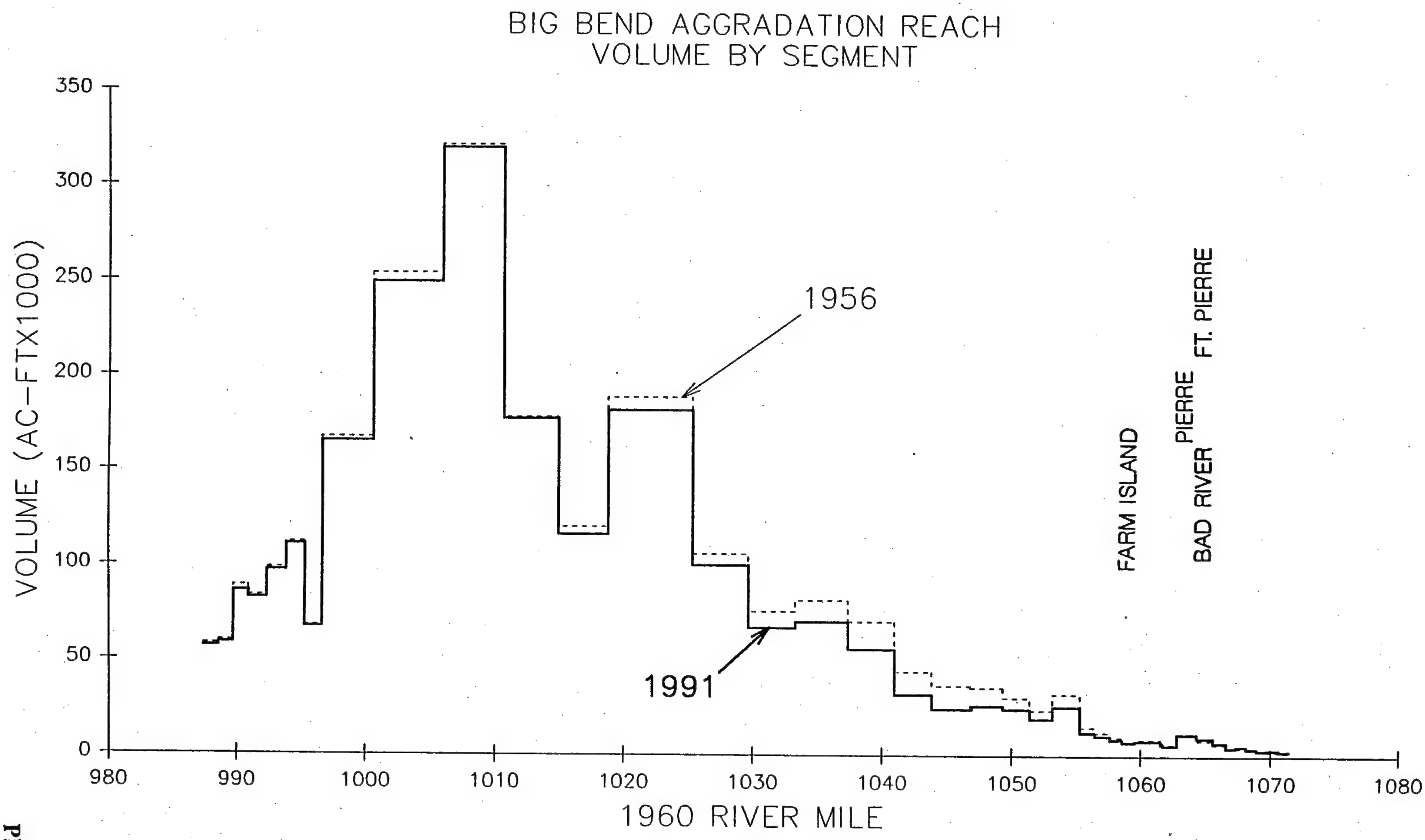


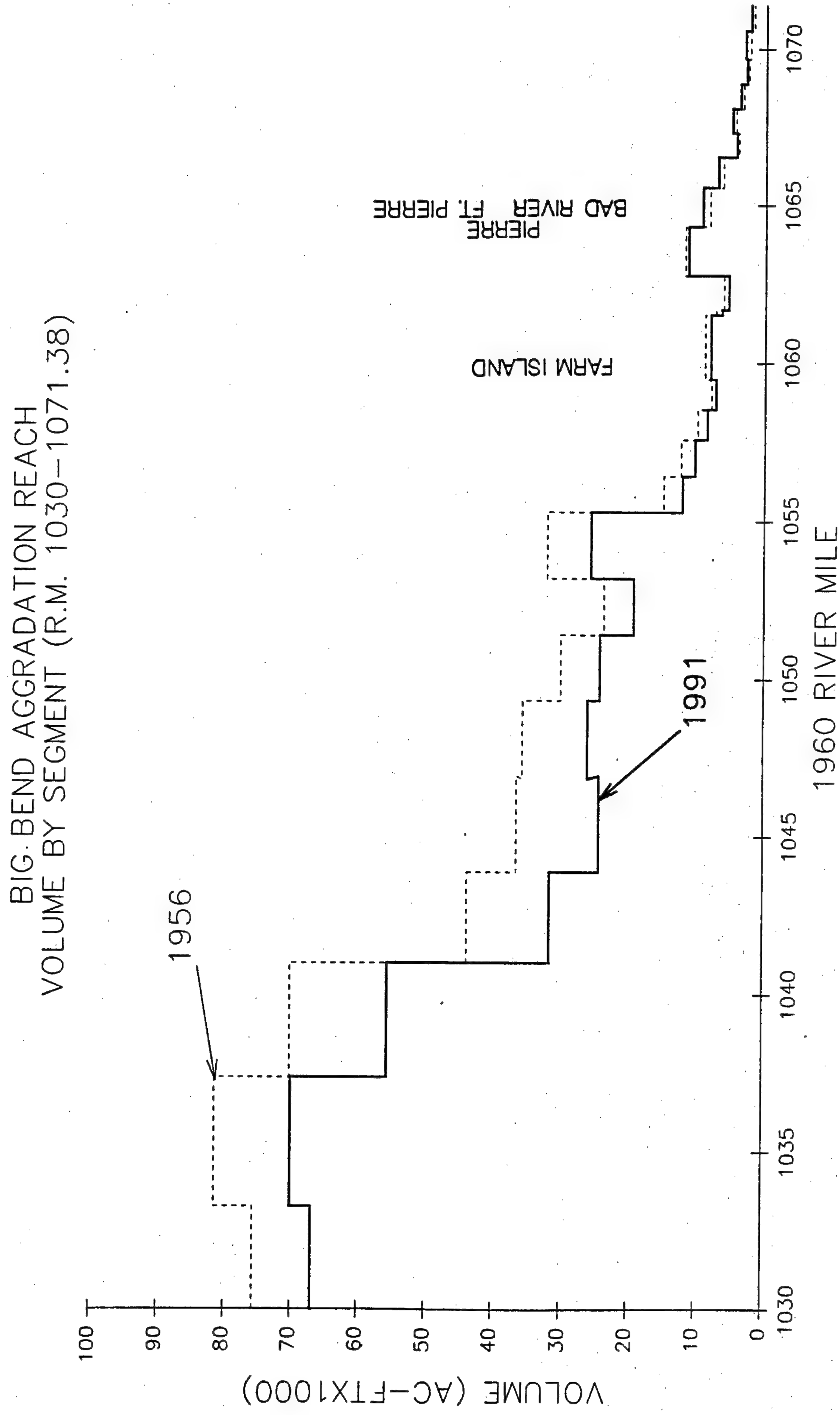
BIG BEND AGGRADATION REACH
THALWEG PROFILE



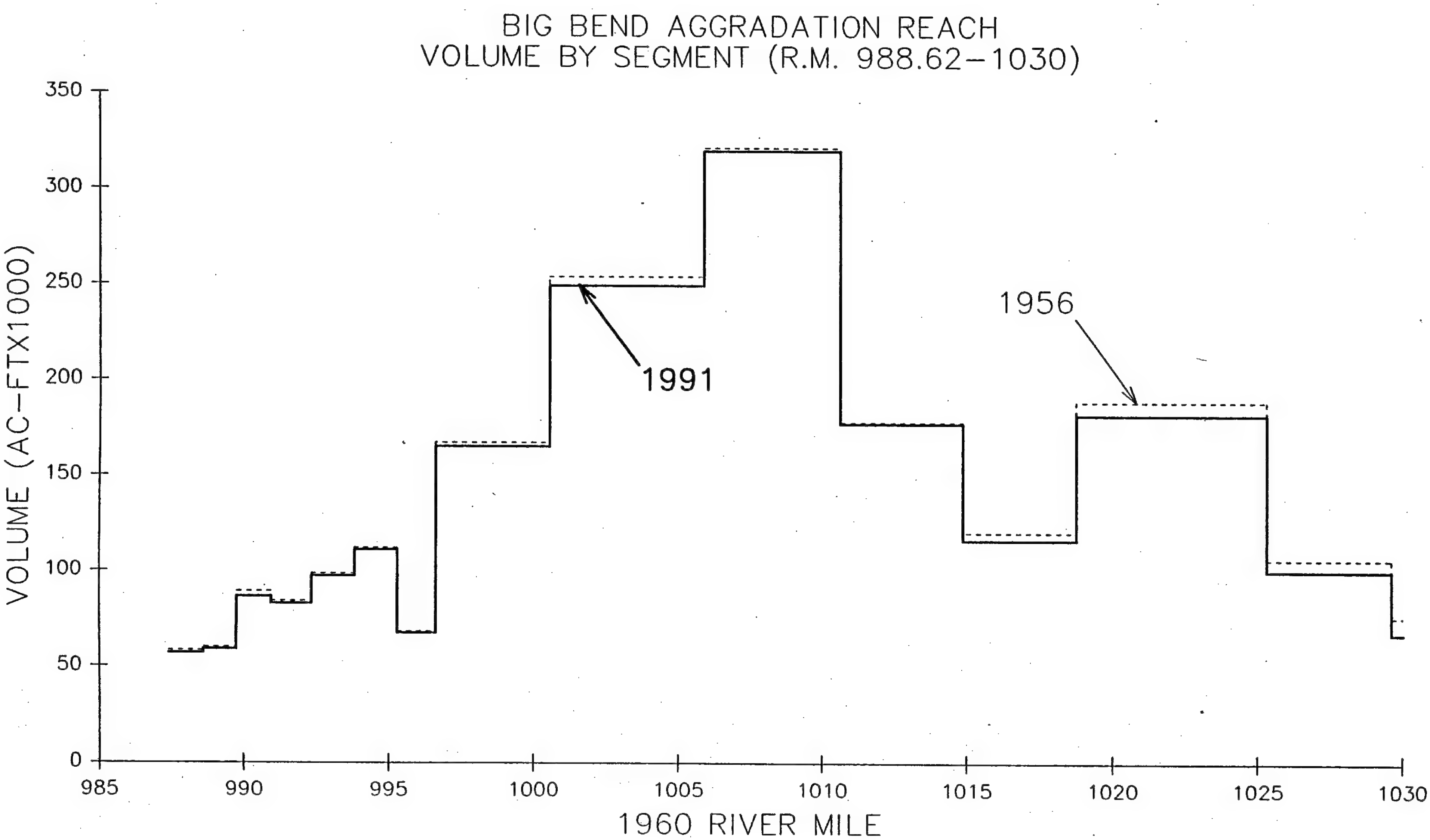


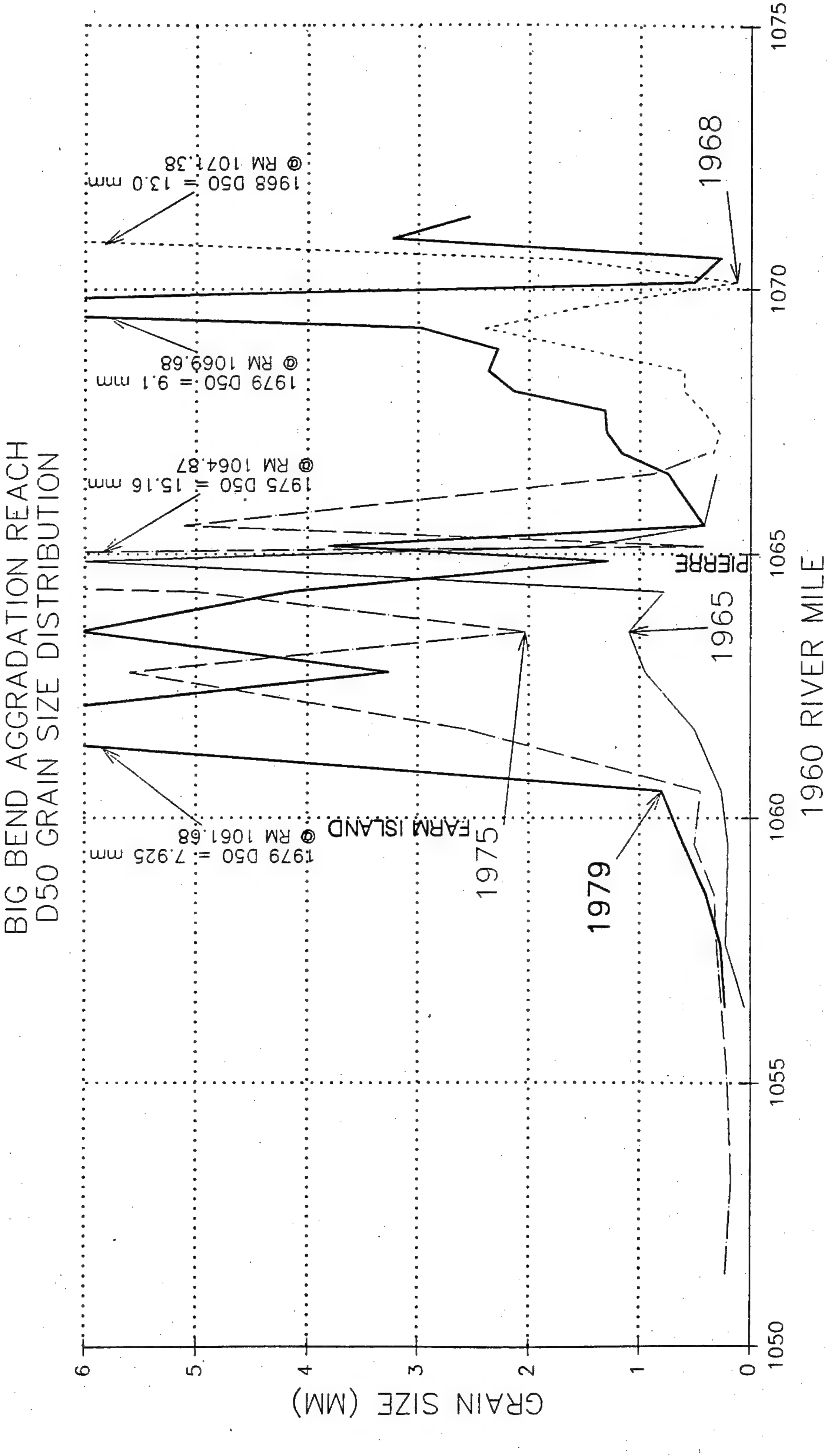
BIG BEND AGGRADATION STUDY
AVERAGE BED PROFILE
ELEVATION (FEET M.S.L.)
1420
1410
1400
1390
1380
1370
1360
980
990
1000
1010
1020
1030
1040
1050
1060
1070
1080
1960 RIVER MILE
1983
1991
1963
1975
BIG BEND DAM
FARM ISLAND
BAD RIVER
PIERRE
FT. PIERRE

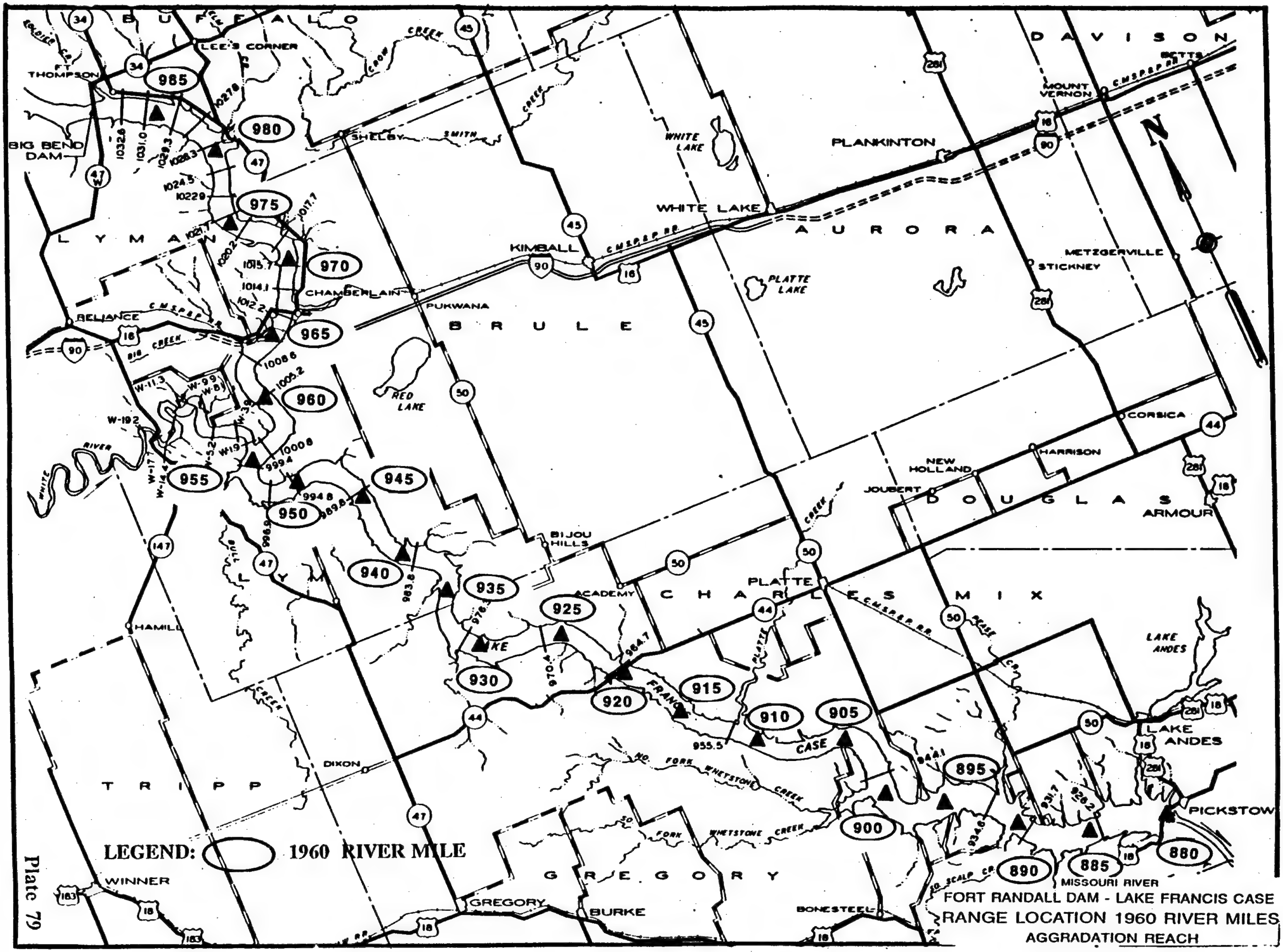

BIG BEND AGGRADATION REACH
VOLUME BY SEGMENT
VOLUME (AC-FTX1000)
350
300
250
200
150
100
50
0
980
990
1000
1010
1020
1030
1040
1050
1060
1070
1080
1960 RIVER MILE
1956
1991
FARM ISLAND
BAD RIVER
PIERRE
FT. PIERRE



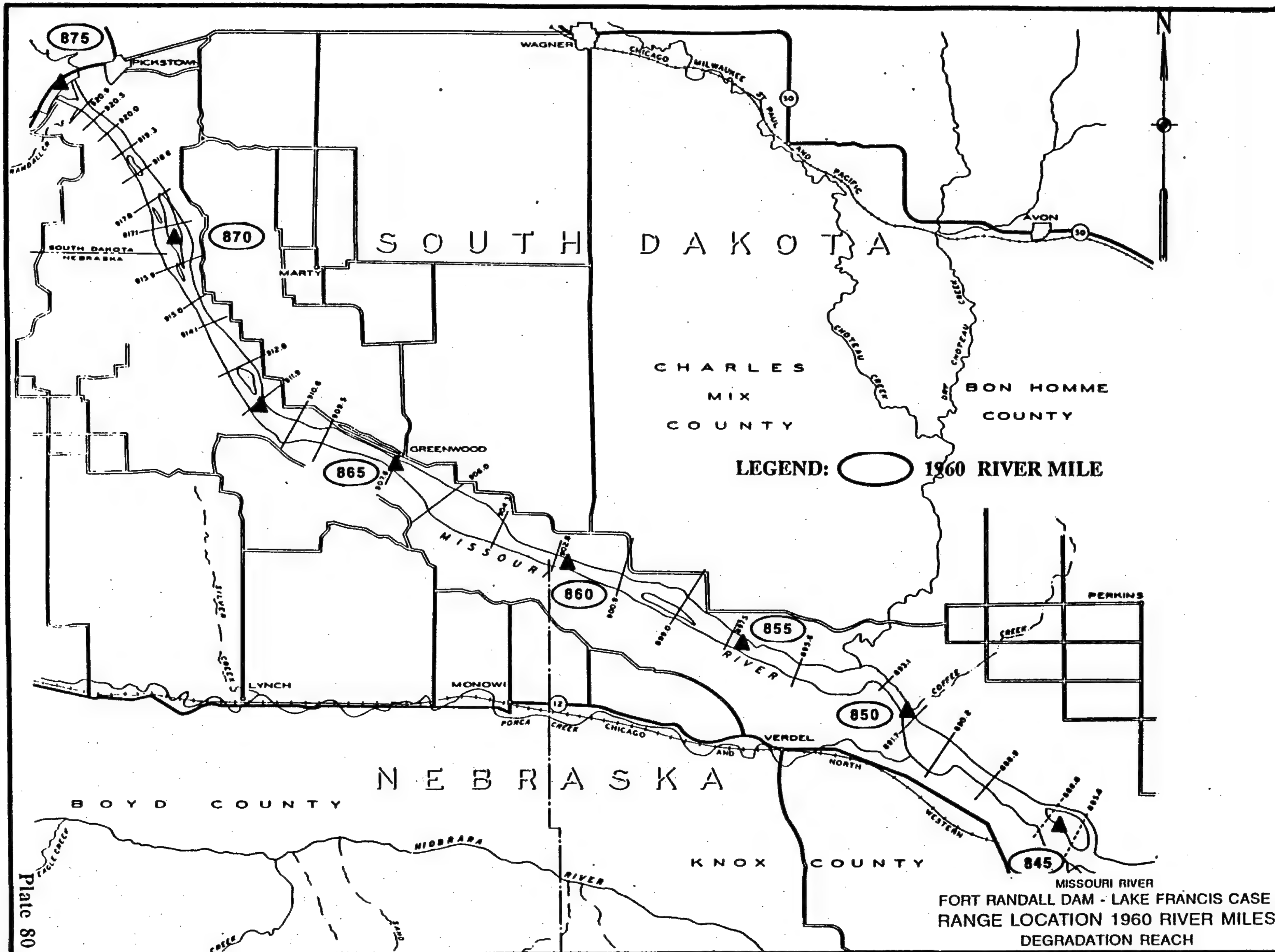
BIG BEND AGGRADATION REACH
VOLUME BY SEGMENT (R.M. 1030–1071.38)
1956
1991
FARM ISLAND
BAD RIVER
PIERRE
FT. PIERRE
VOLUME (AC-FTX1000)
0
10
20
30
40
50
60
70
80
90
100
1960 RIVER MILE
1030
1035
1040
1045
1050
1055
1060
1065
1070


BIG BEND AGGRADATION REACH
VOLUME BY SEGMENT (R.M. 988.62–1030)
VOLUME (AC–FTX1000)
0
50
100
150
200
250
300
350
985
990
995
1000
1005
1010
1015
1020
1025
1030
1960 RIVER MILE
1991
1956


BIG BEND AGGRADATION REACH
D50 GRAIN SIZE DISTRIBUTION
1968 D50 = 13.0 mm
@ RM 1071.38
1979 D50 = 9.1 mm
@ RM 1069.68
1975 D50 = 15.16 mm
@ RM 1064.87
1979 D50 = 7.925 mm
@ RM 1061.68
FARM ISLAND
PIERRE
1968
1965
1975
1979
GRAIN SIZE (MM)
0
1
2
3
4
5
6
1050
1055
1060
1065
1070
1075
1960 RIVER MILE

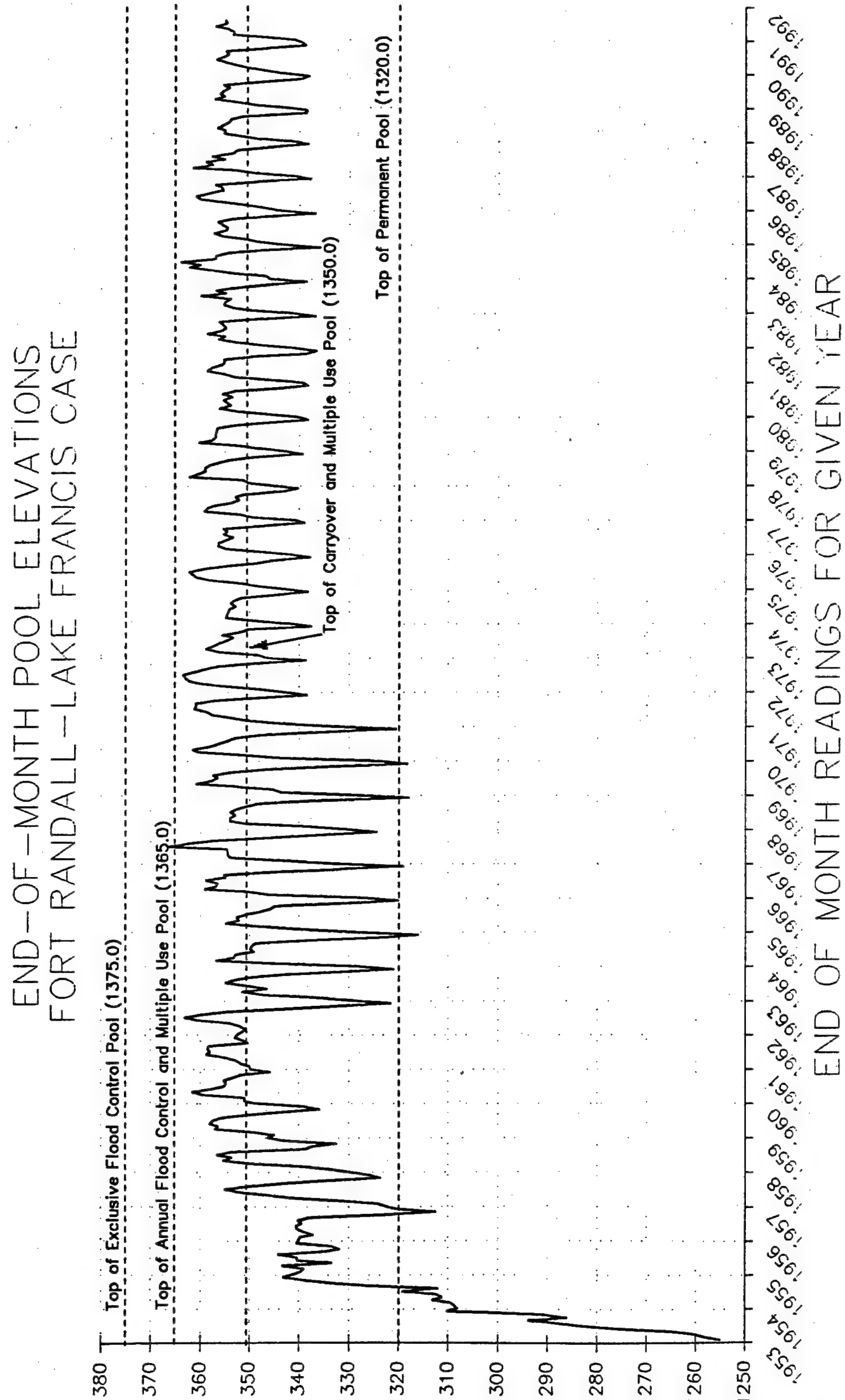


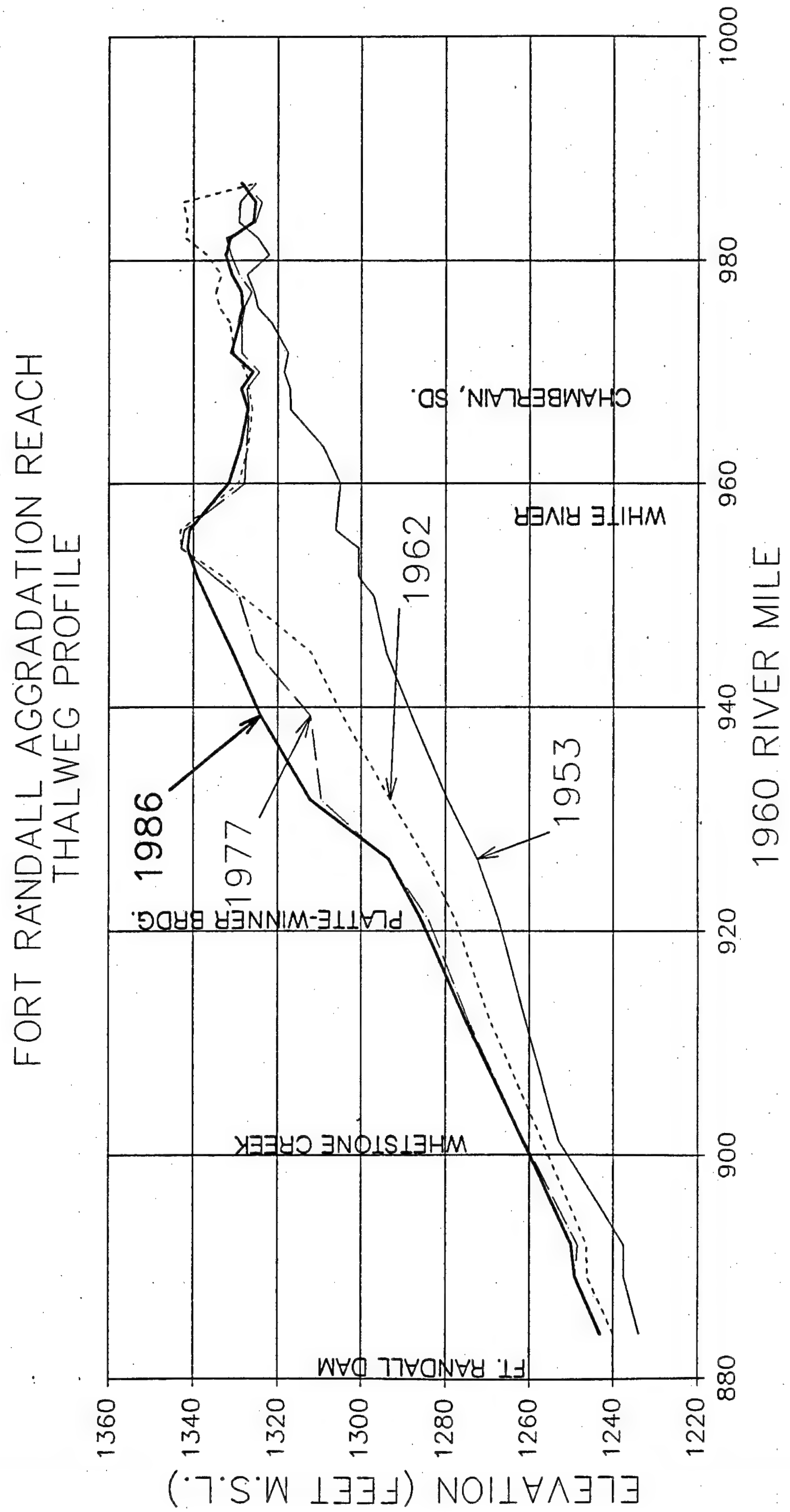
FORT RANDALL DAM - LAKE FRANCIS CASE
RANGE LOCATION 1960 RIVER MILES
AGGRADATION REACH

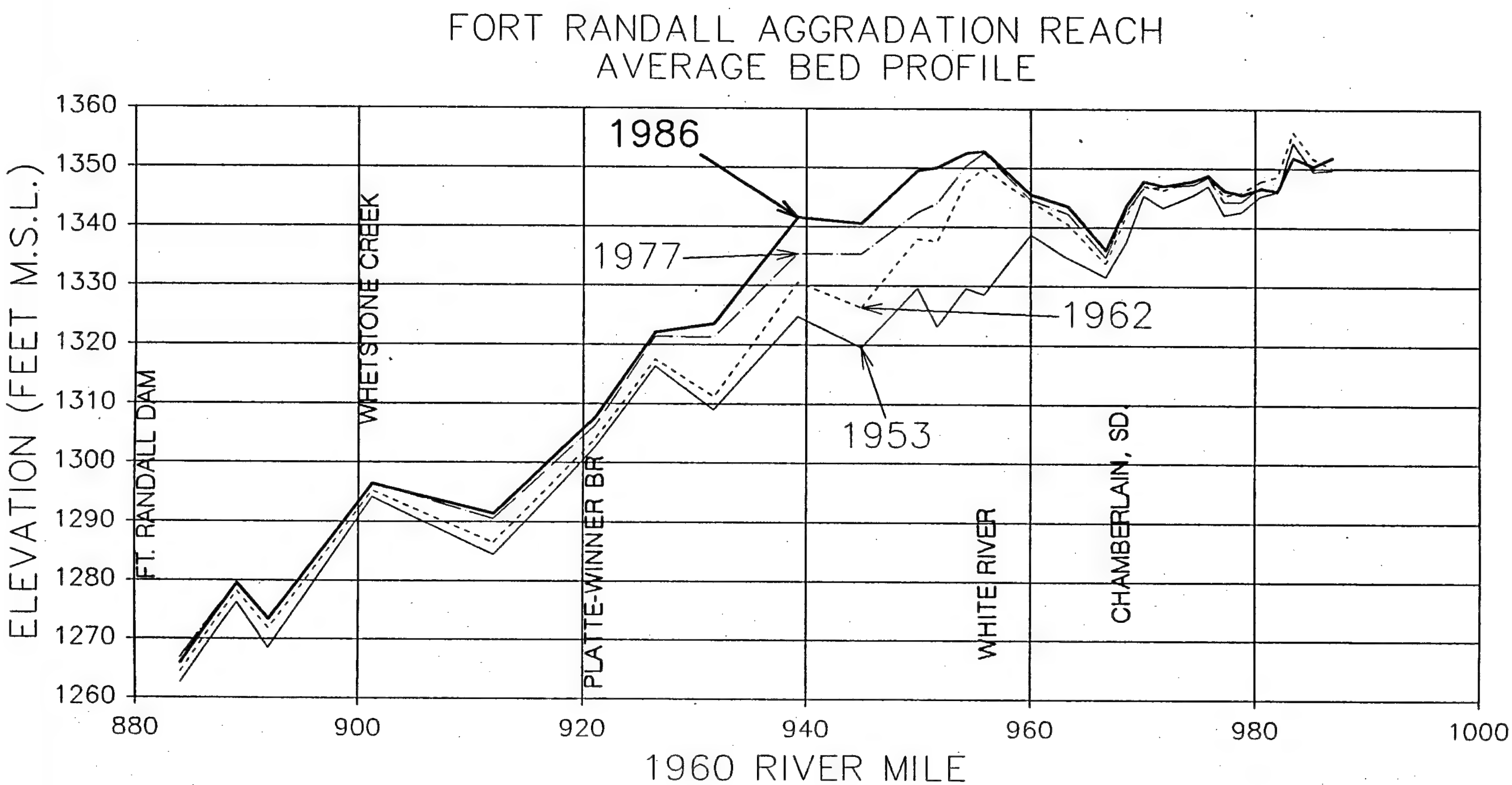


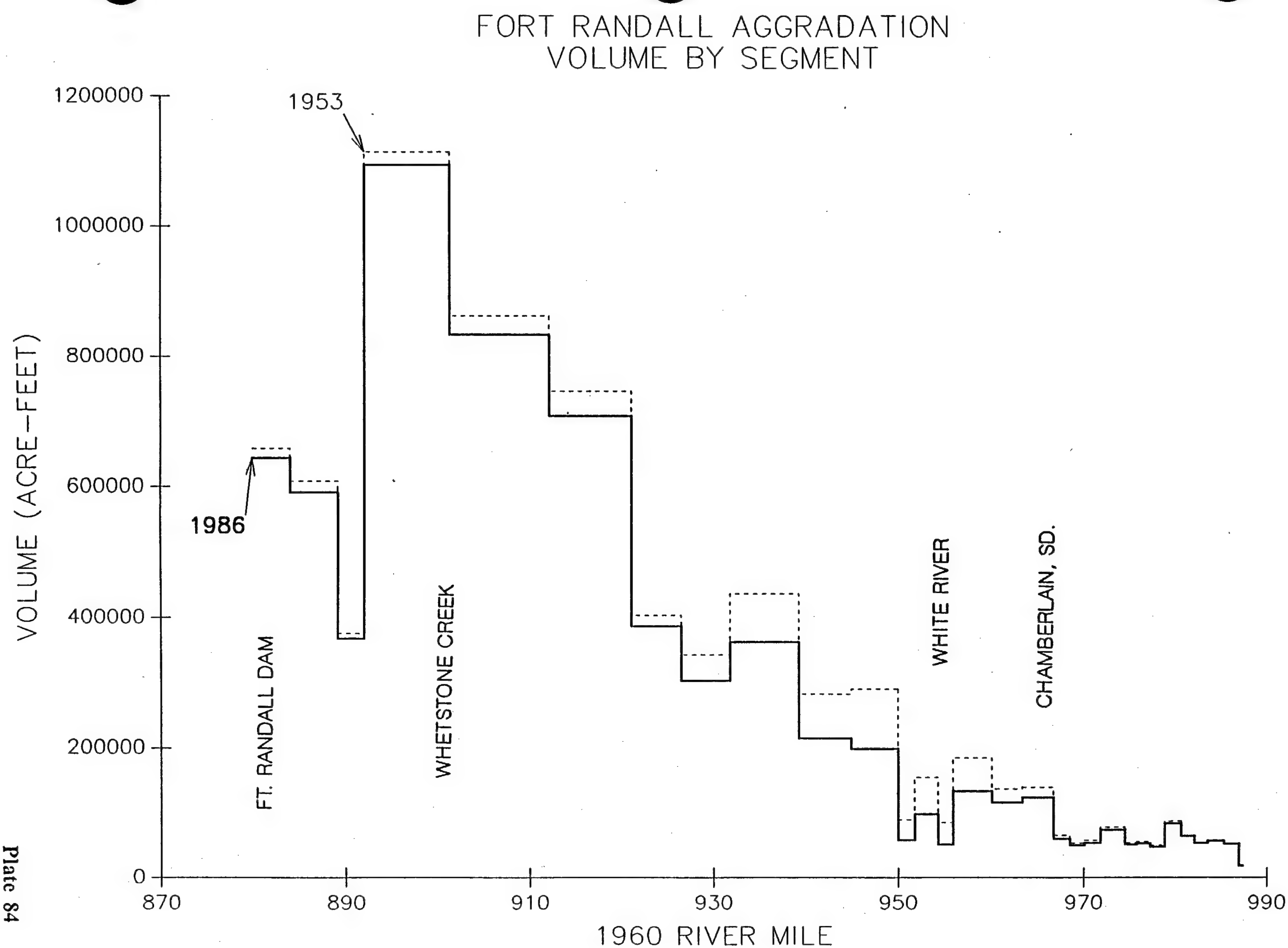
MISSOURI RIVER
FORT RANDALL DAM - LAKE FRANCIS CASE
RANGE LOCATION 1960 RIVER MILES
DEGRADATION REACH

Plate 80

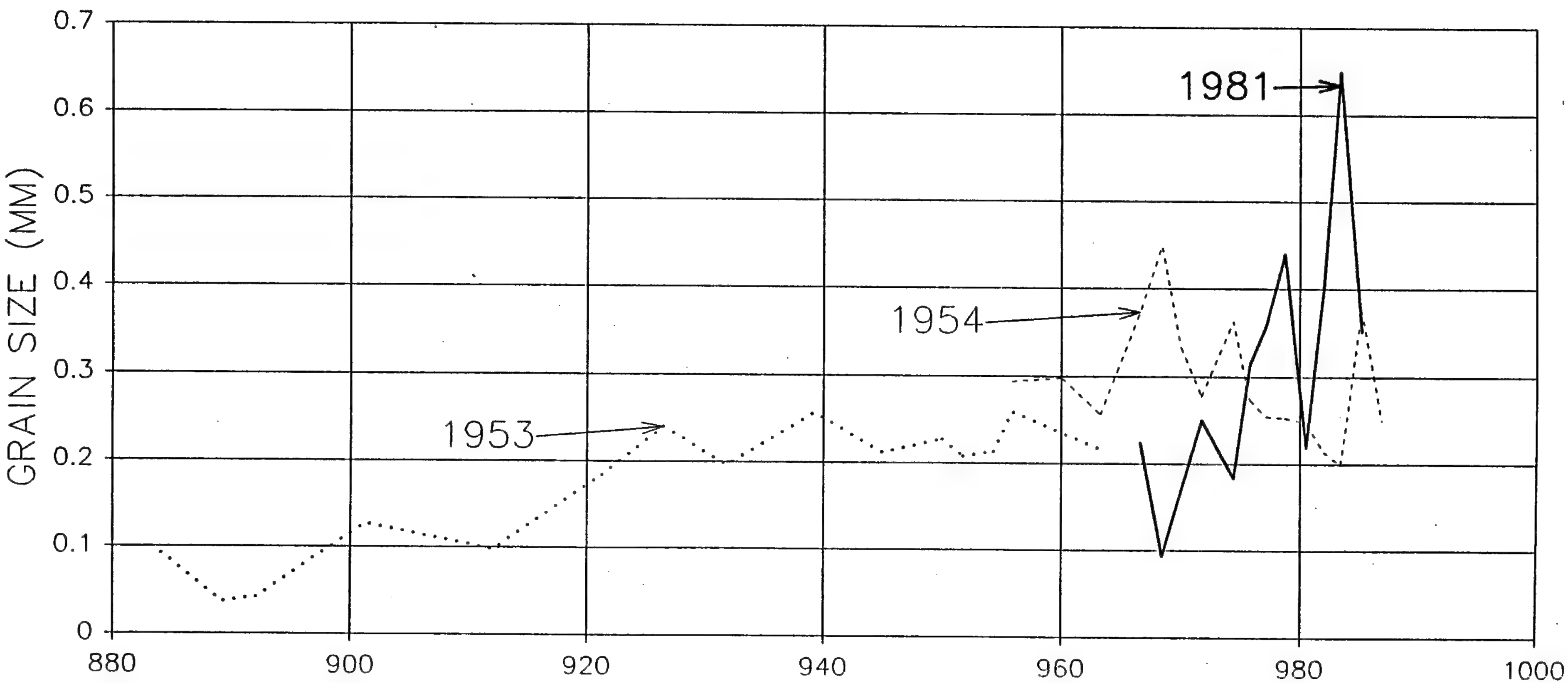

END-OF-MONTH POOL ELEVATIONS
FORT RANDALL-LAKE FRANCIS CASE
POOL ELEVATION (FEET)
END OF MONTH READINGS FOR GIVEN YEAR
Top of Exclusive Flood Control Pool (1375.0)
Top of Annual Flood Control and Multiple Use Pool (1365.0)
Top of Carryover and Multiple Use Pool (1350.0)
Top of Permanent Pool (1320.0)
1380
1370
1360
1350
1340
1330
1320
1310
1300
1290
1280
1270
1260
1250
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992


FORT RANDALL AGGRADATION REACH
THALWEG PROFILE
ELEVATION (FEET M.S.L.)
1960 RIVER MILE
1360
1340
1320
1300
1280
1260
1240
1220
880
900
920
940
960
980
1000
FT. RANDALL DAM
WHETSTONE CREEK
PLATTE-WINNER BRDG.
WHITE RIVER
CHAMBERLAIN, SD.
1986
1977
1962
1953

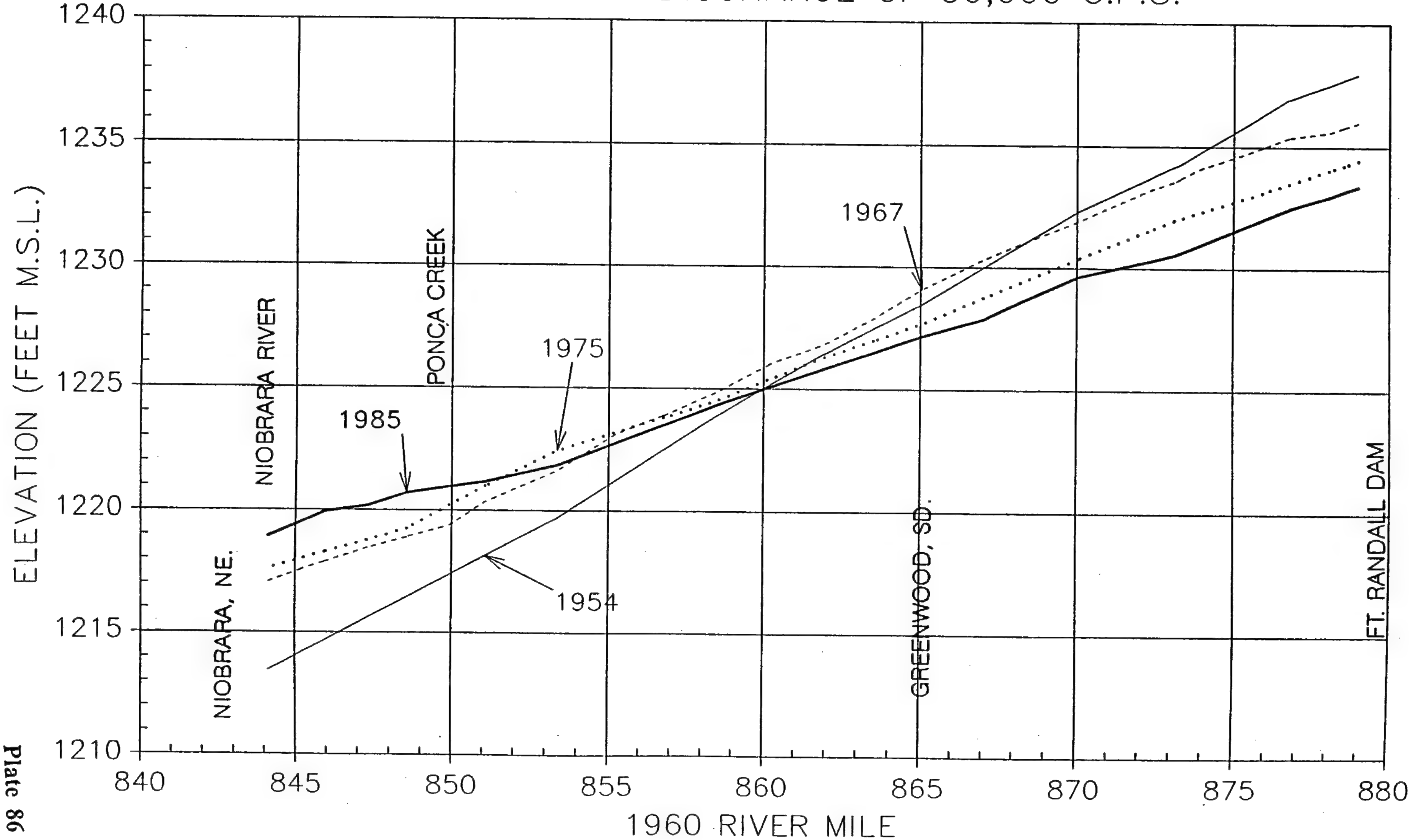

FORT RANDALL AGGRADATION REACH
AVERAGE BED PROFILE
1986
1977
1962
1953
FT. RANDALL DAM
WHETSTONE CREEK
PLATTE-WINNER BR
WHITE RIVER
CHAMBERLAIN, SD.
ELEVATION (FEET M.S.L.)
1360
1350
1340
1330
1320
1310
1300
1290
1280
1270
1260
880
900
920
940
960
980
1000
1960 RIVER MILE


FORT RANDALL AGGRADATION
VOLUME BY SEGMENT
VOLUME (ACRE-FEET)
1200000
1000000
800000
600000
400000
200000
0
870
890
910
930
950
970
990
1960 RIVER MILE
1953
1986
FT. RANDALL DAM
WHETSTONE CREEK
WHITE RIVER
CHAMBERLAIN, SD.

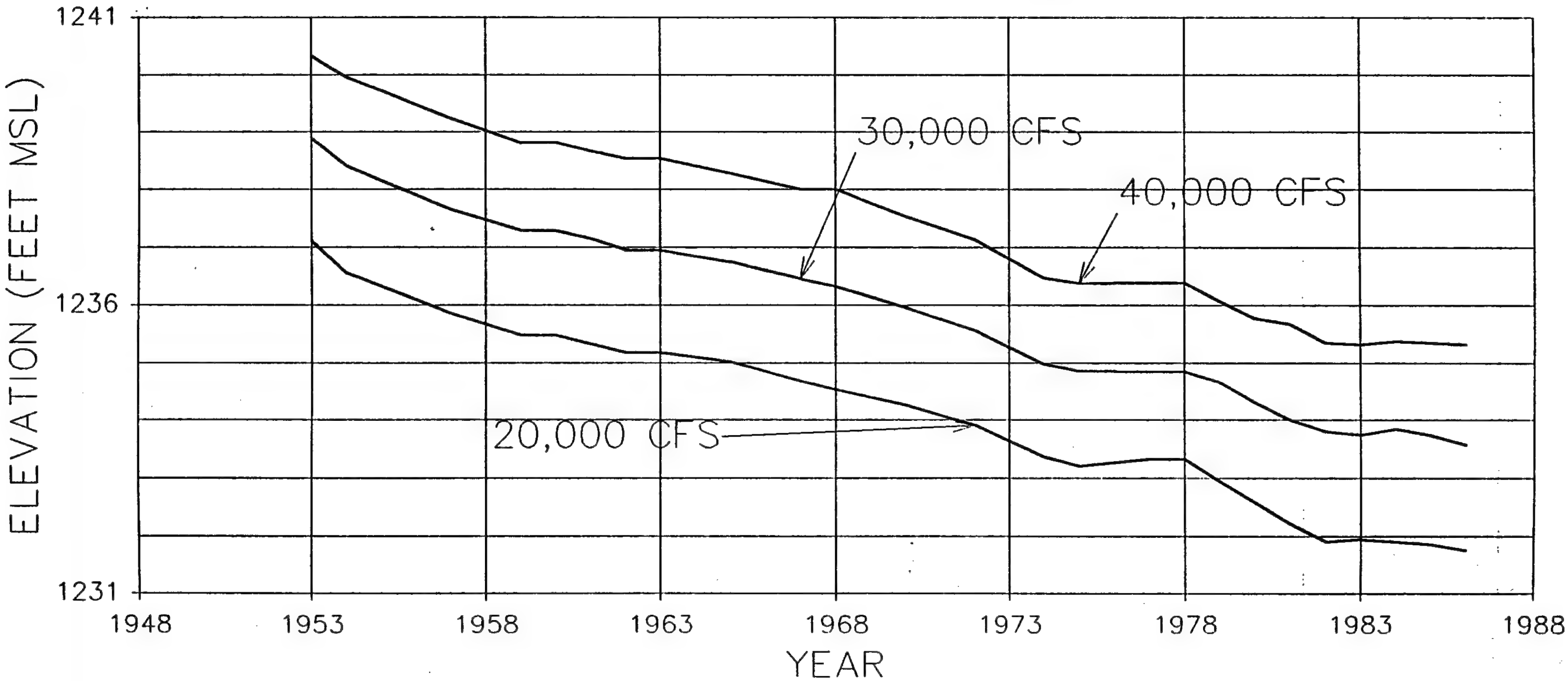
FORT RANDALL AGGRADATION REACH
D50 GRAIN SIZE DISTRIBUTION

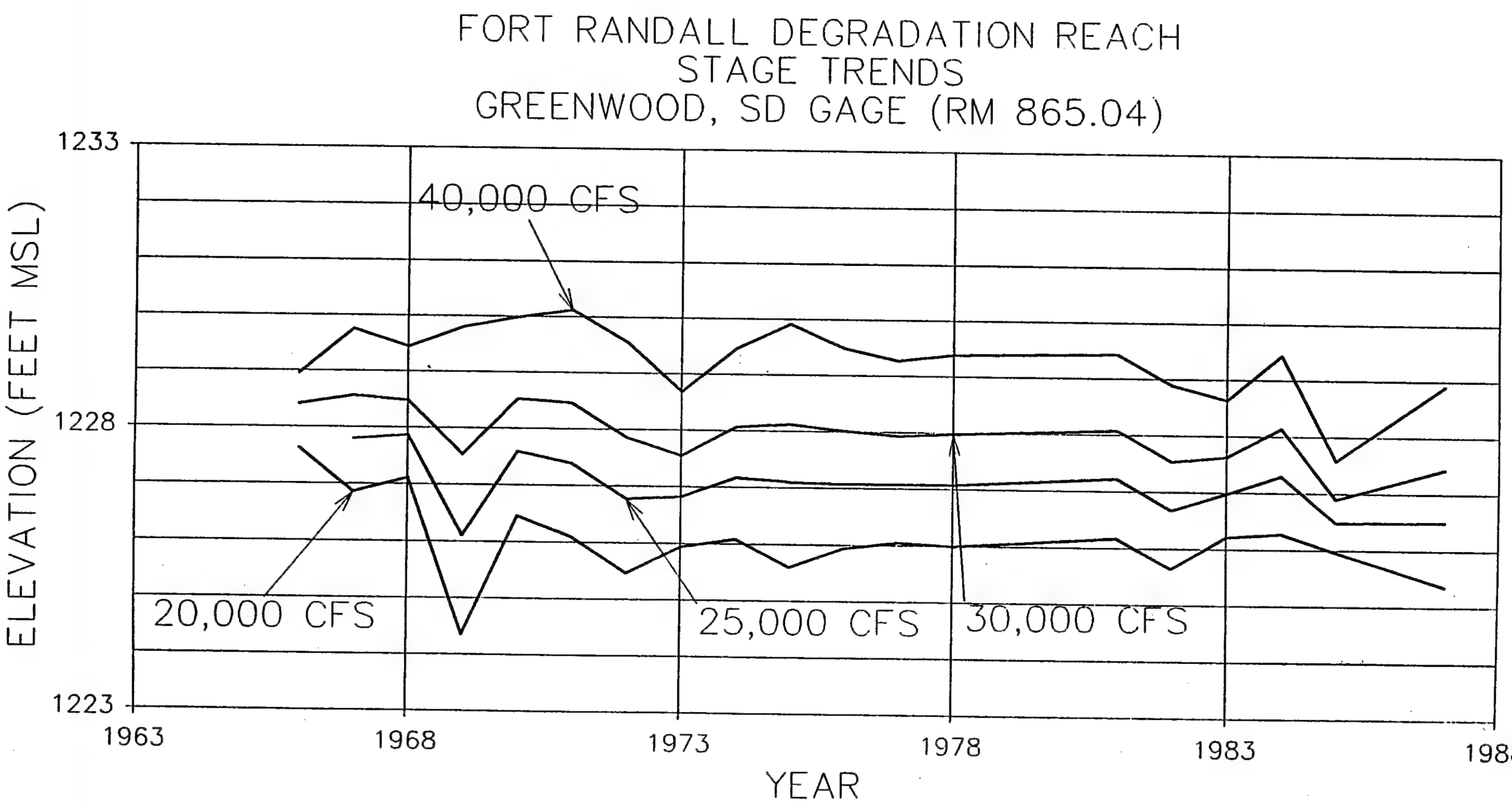


MISSOURI RIVER BELOW FORT RANDALL
WATER SURFACE PROFILES
ADJUSTED TO DISCHARGE OF 30,000 C.F.S.

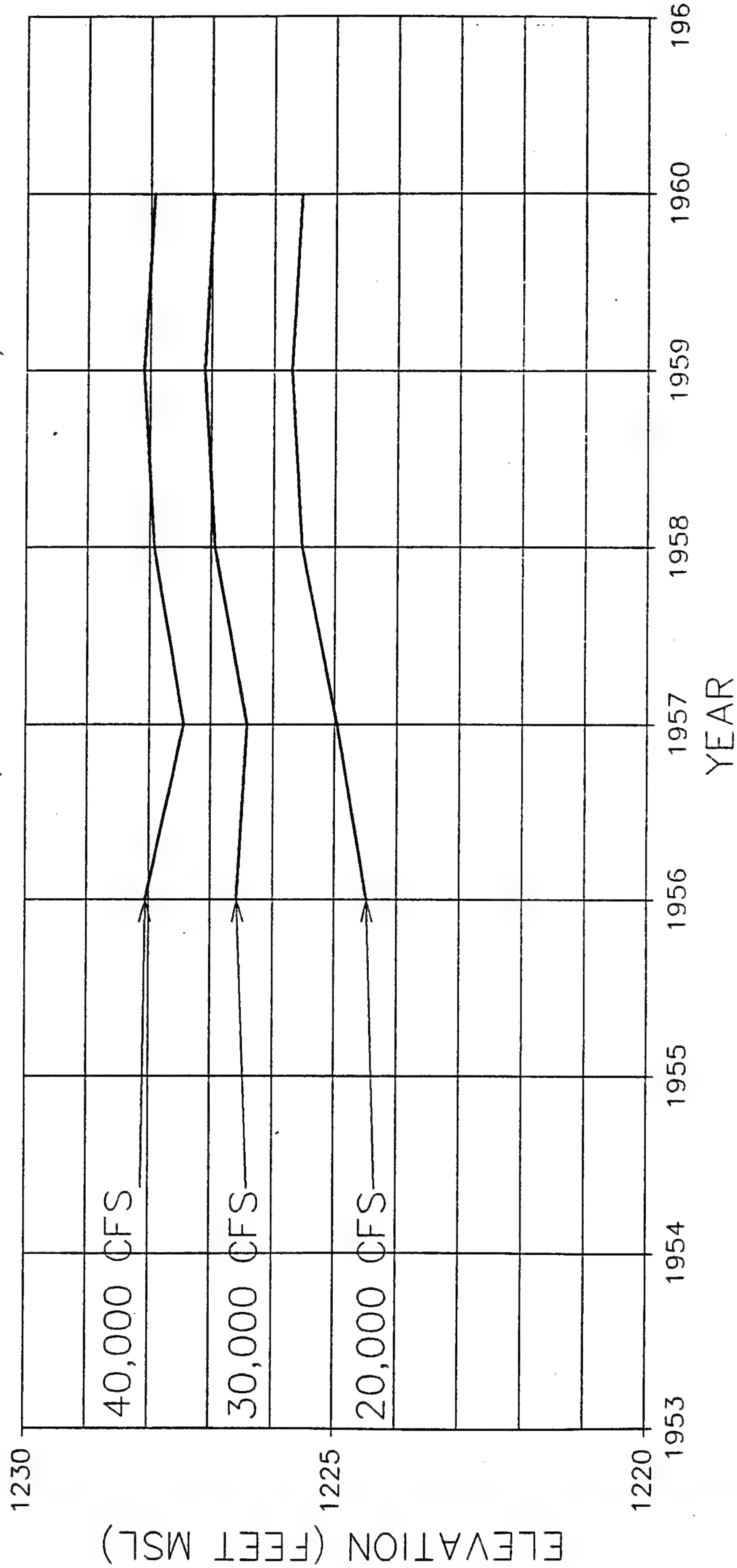


FORT RANDALL DEGRADATION REACH
STAGE TRENDS
FORT RANDALL DAM GAGE (RM 879.98)

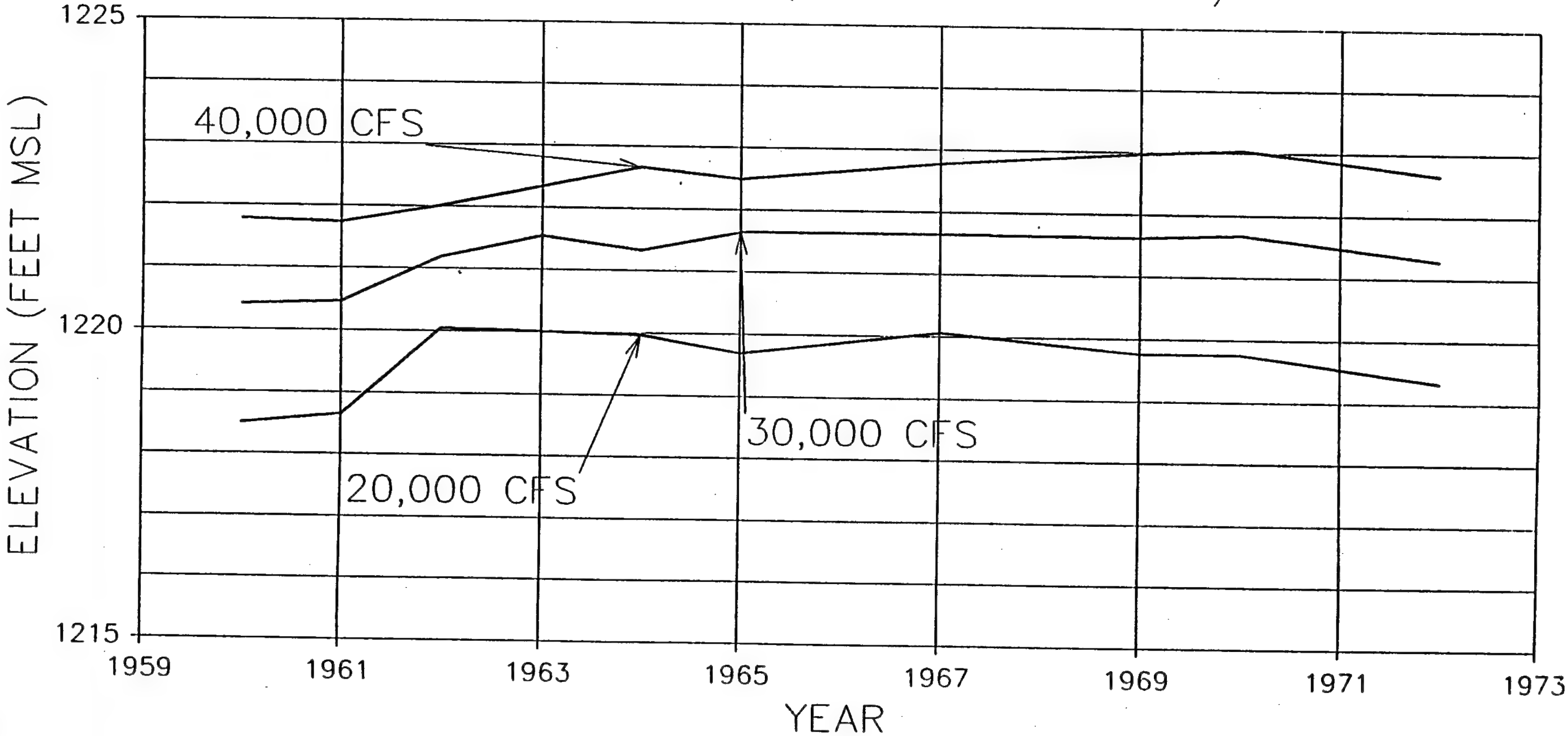


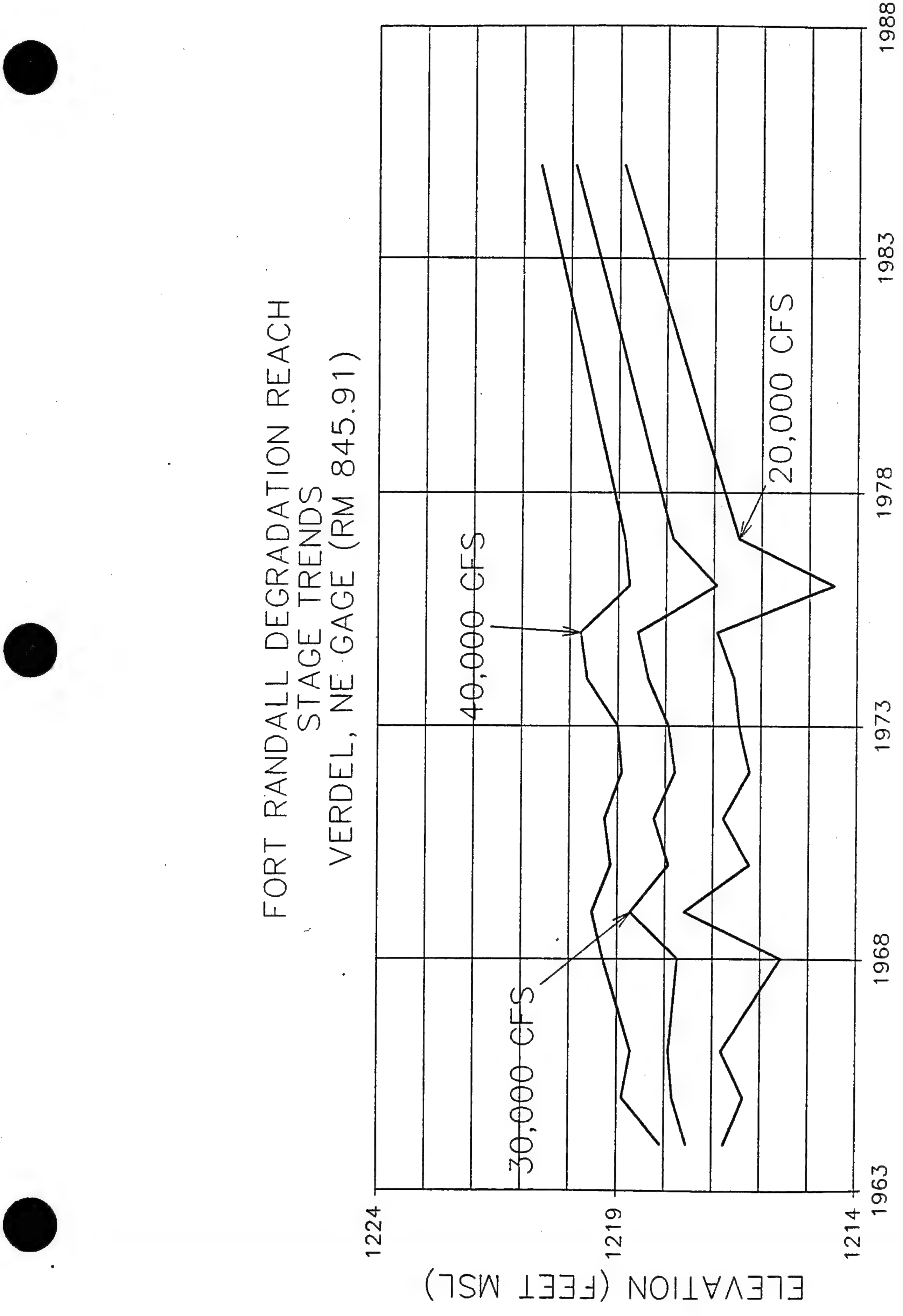

FORT RANDALL DEGRADATION REACH
STAGE TRENDS
GREENWOOD, SD GAGE (RM 865.04)
40,000 CFS
20,000 CFS
25,000 CFS
30,000 CFS
ELEVATION (FEET MSL)
1233
1228
1223
1963
1968
1973
1978
1983
1988
YEAR

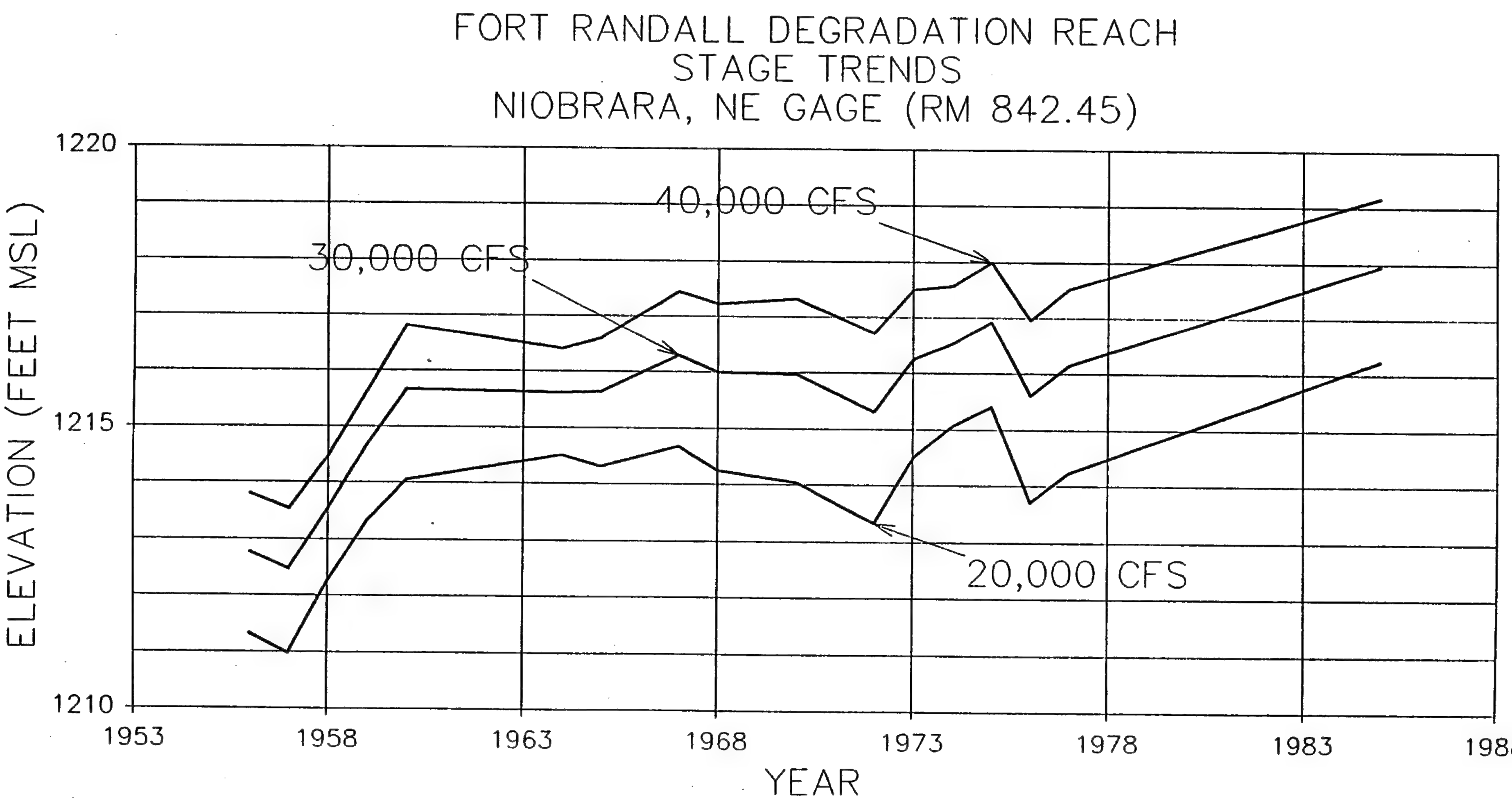
FORT RANDALL DEGRADATION REACH
STAGE TRENDS (GAGE AT RM 861.93)

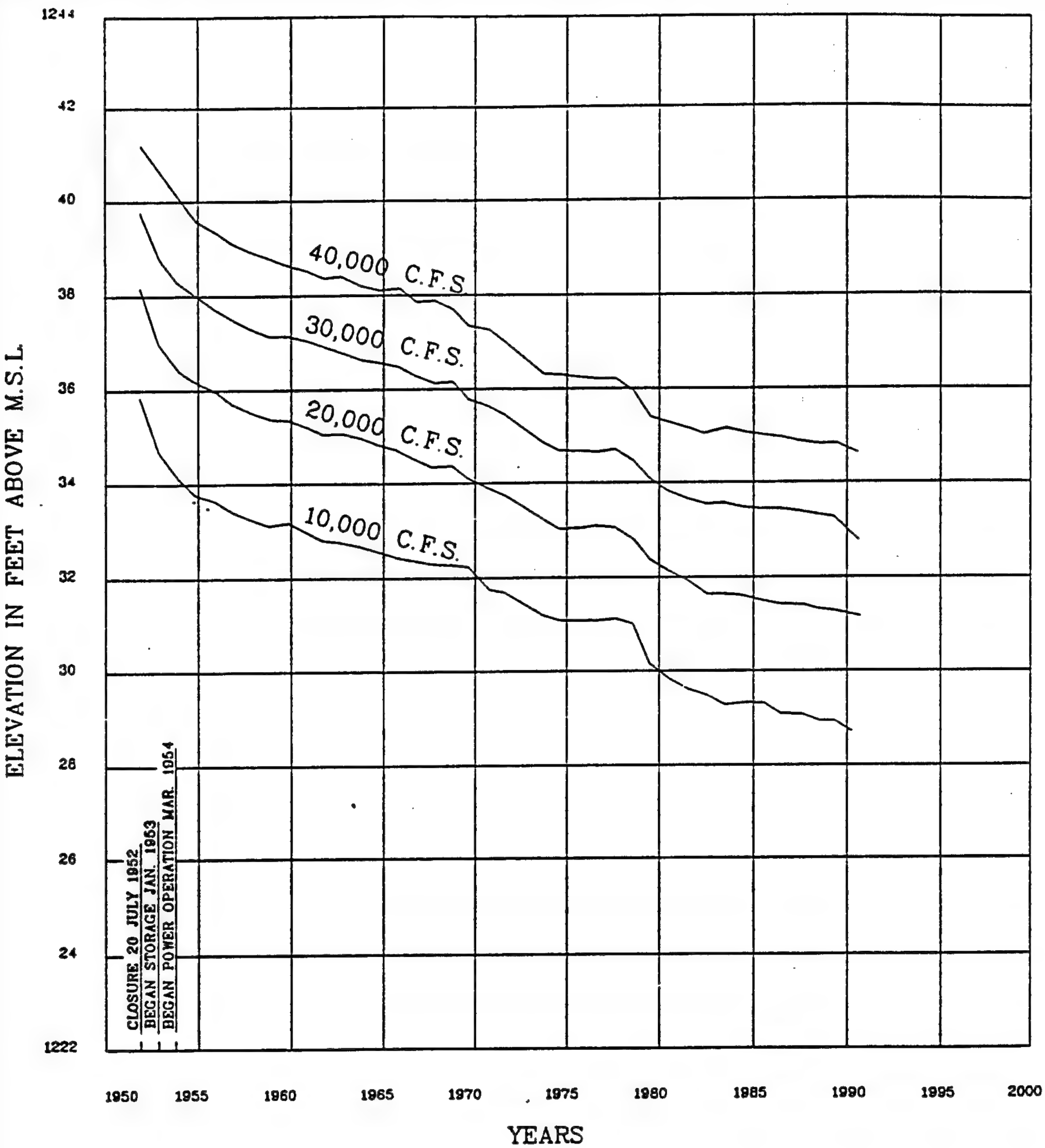


FORT RANDALL DEGRADATION REACH
STAGE TRENDS (GAGE AT RM 853.37)

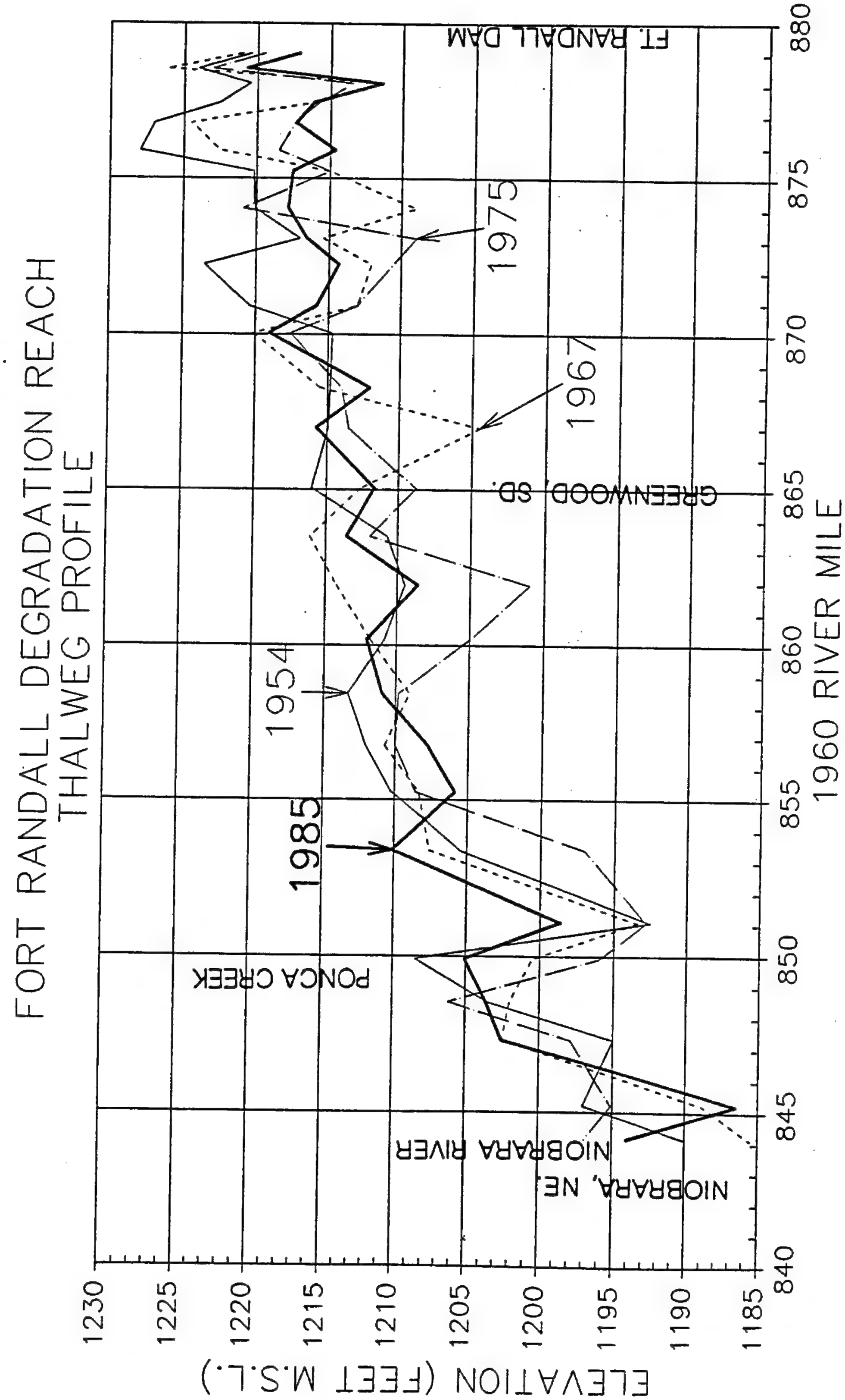



FORT RANDALL DEGRADATION REACH
STAGE TRENDS
VERDEL, NE GAGE (RM 845.91)
40,000 CFS
30,000 CFS
20,000 CFS
YEAR
1963
1968
1973
1978
1983
1988
ELEVATION (FEET MSL)
1214
1219
1224

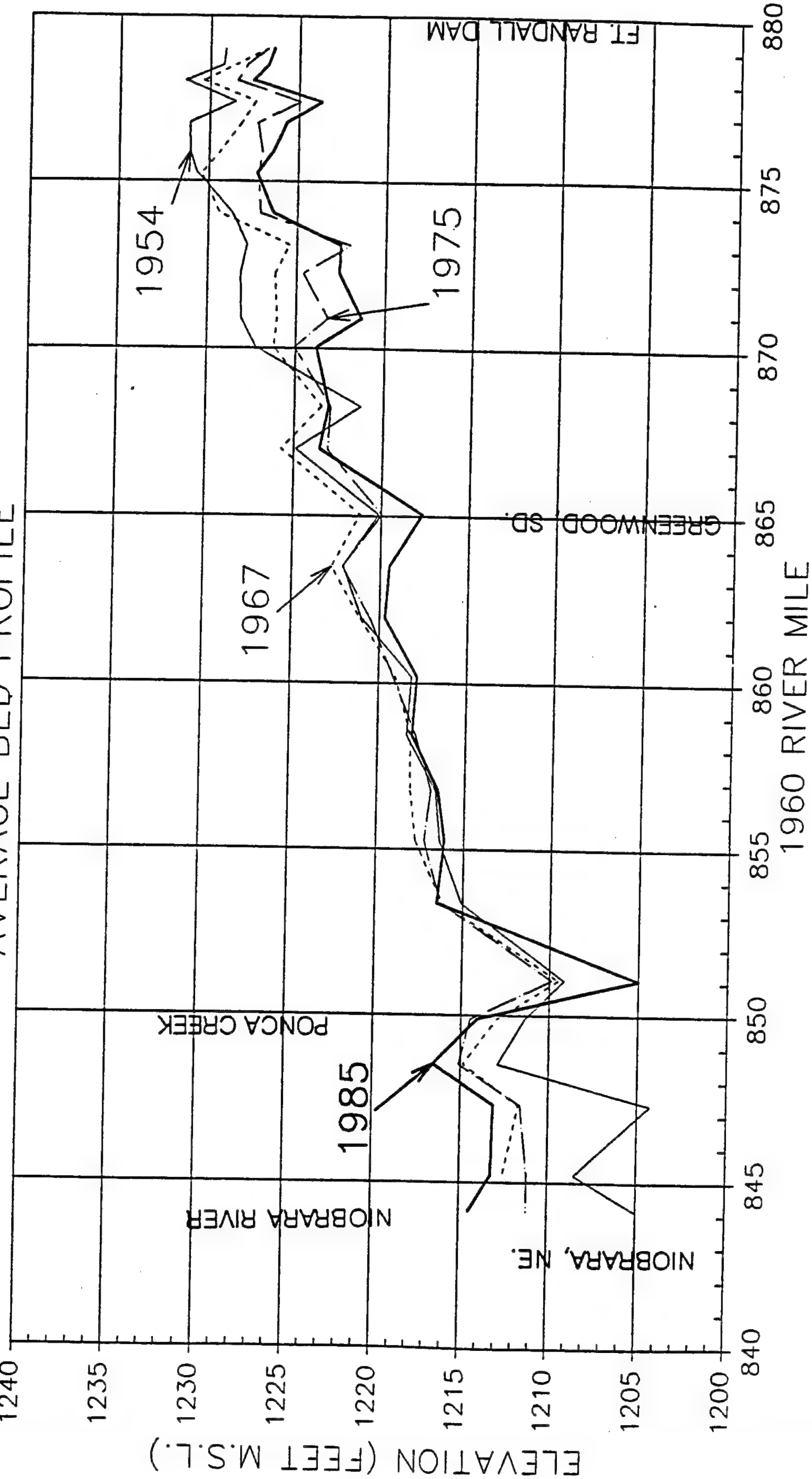

FORT RANDALL DEGRADATION REACH
STAGE TRENDS
NIOBRARA, NE GAGE (RM 842.45)
40,000 CFS
30,000 CFS
20,000 CFS
ELEVATION (FEET MSL)
1220
1215
1210
1953
1958
1963
1968
1973
1978
1983
1988
YEAR

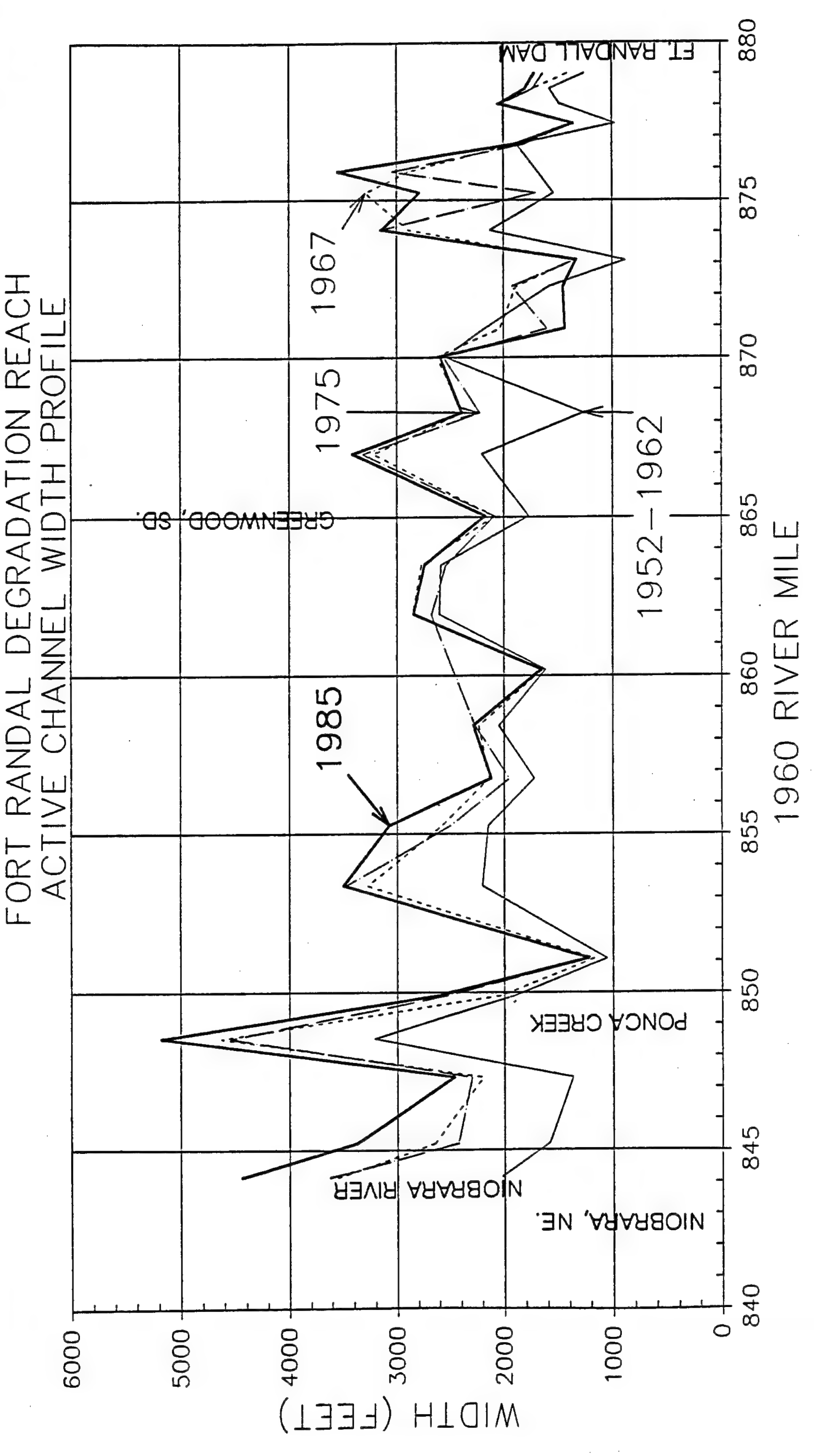


MISSOURI RIVER
FORT RANDALL PROJECT
TAILWATER TRENDS
U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA
MARCH 1992


FORT RANDALL DEGRADATION REACH
THALWEG PROFILE
ELEVATION (FEET M.S.L.)
1960 RIVER MILE
1230
1225
1220
1215
1210
1205
1200
1195
1190
1185
840
845
850
855
860
865
870
875
880
NIOBRARA, NE.
NIOBRARA RIVER
PONCA CREEK
GREENWOOD, SD.
FT. RANDALL DAM
1985
1954
1967
1975

FORT RANDALL DEGRADATION REACH
AVERAGE BED PROFILE





FORT RANDAL DEGRADATION REACH
ACTIVE CHANNEL WIDTH PROFILE
WIDTH (FEET)
6000
5000
4000
3000
2000
1000
0
840
845
850
855
860
865
870
875
880
1960 RIVER MILE
FT. RANDALL DAM
1967
1975
1952—1962
GREENWOOD, SD.
1985
PONCA CREEK
NIOBRARA RIVER
NIOBRARA, NE.

Plate 96

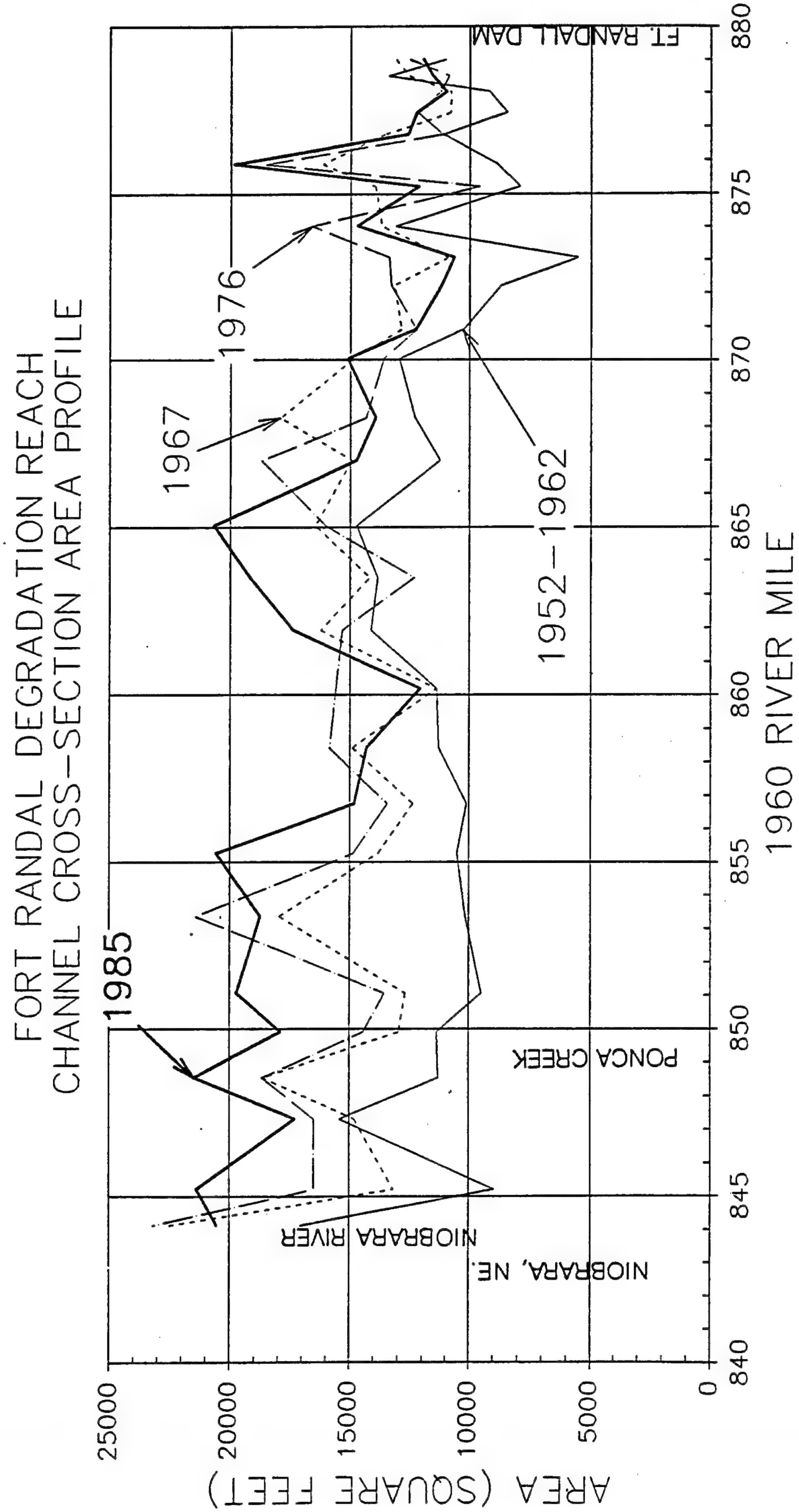
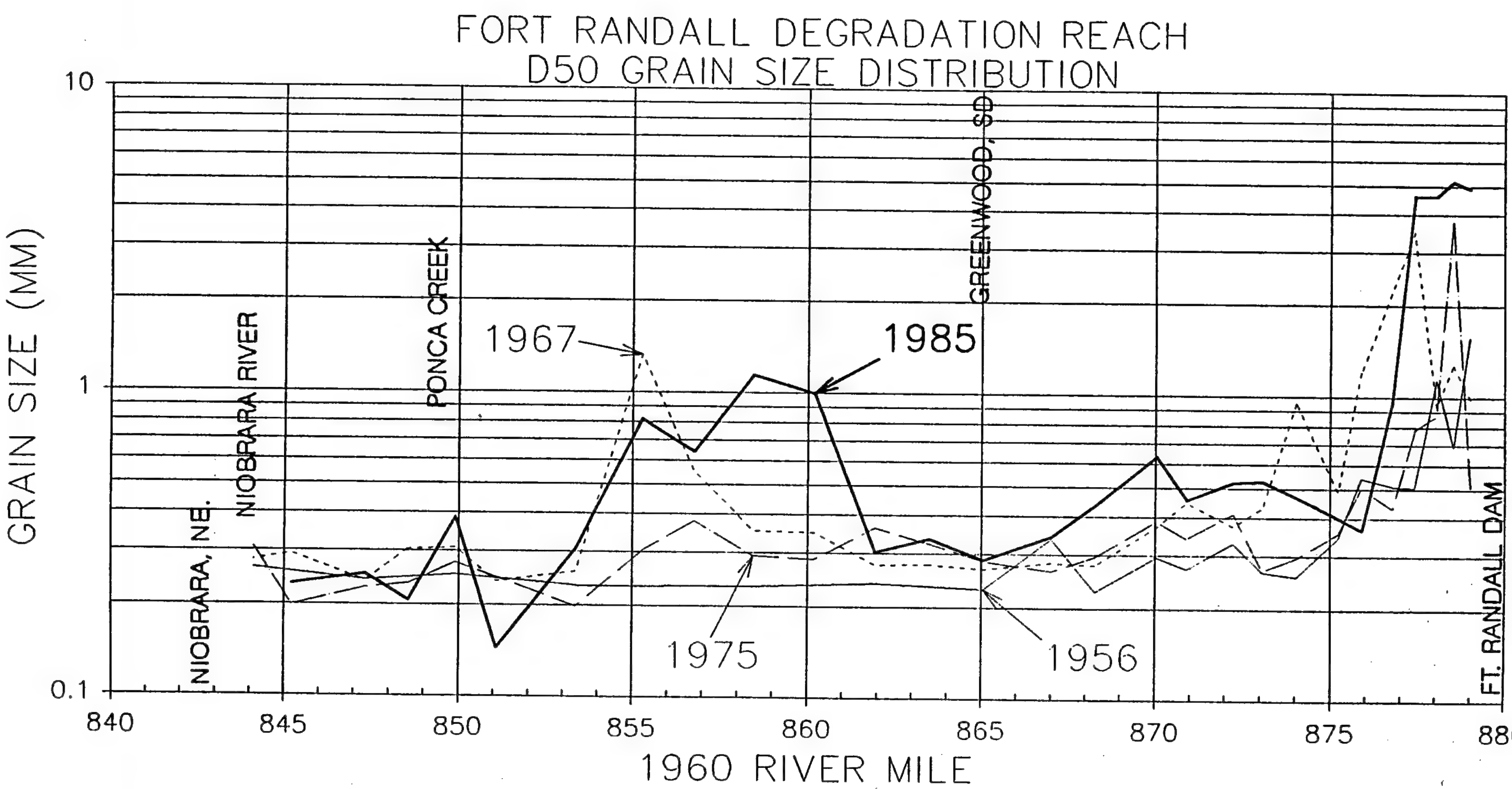
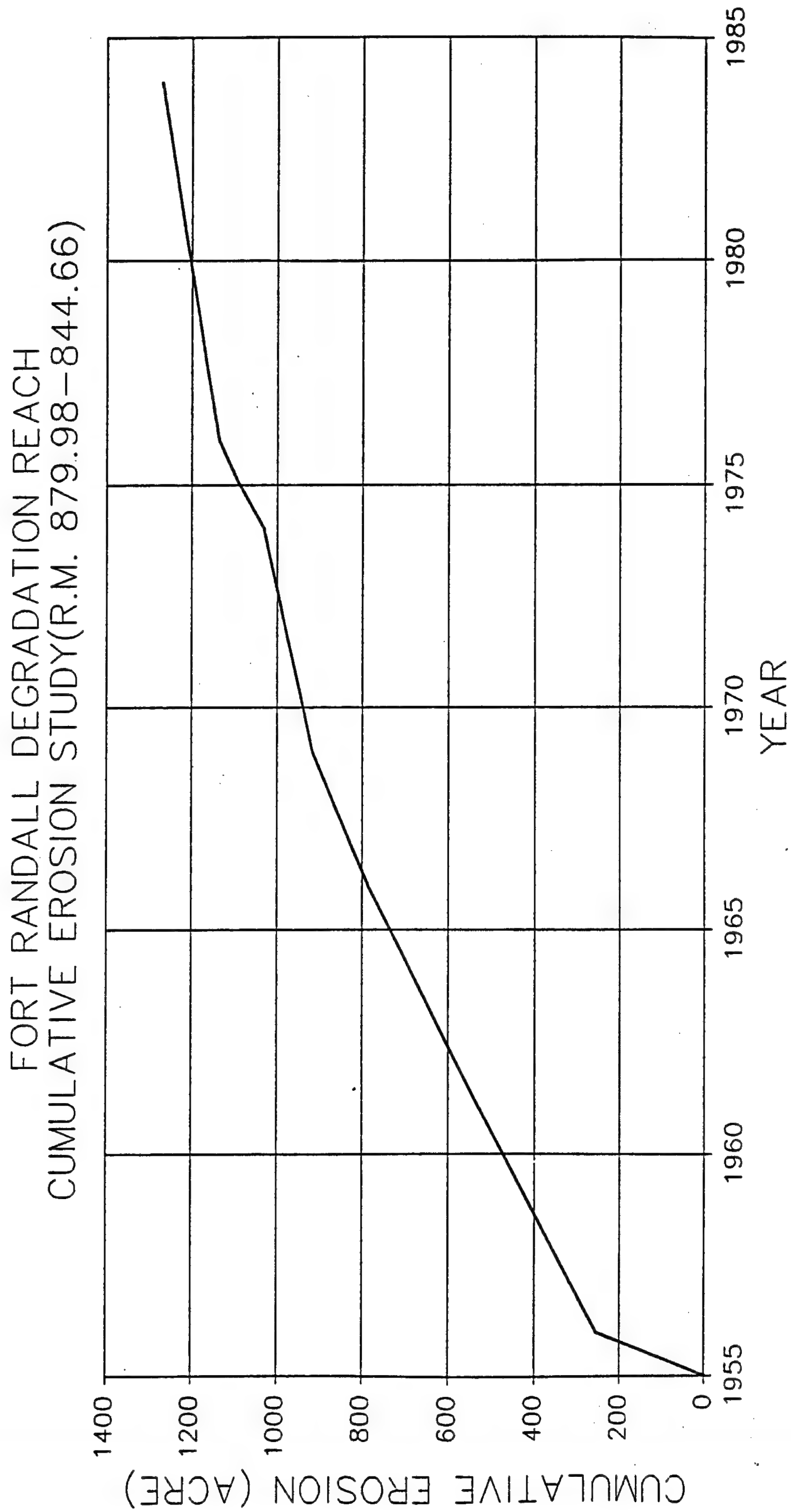
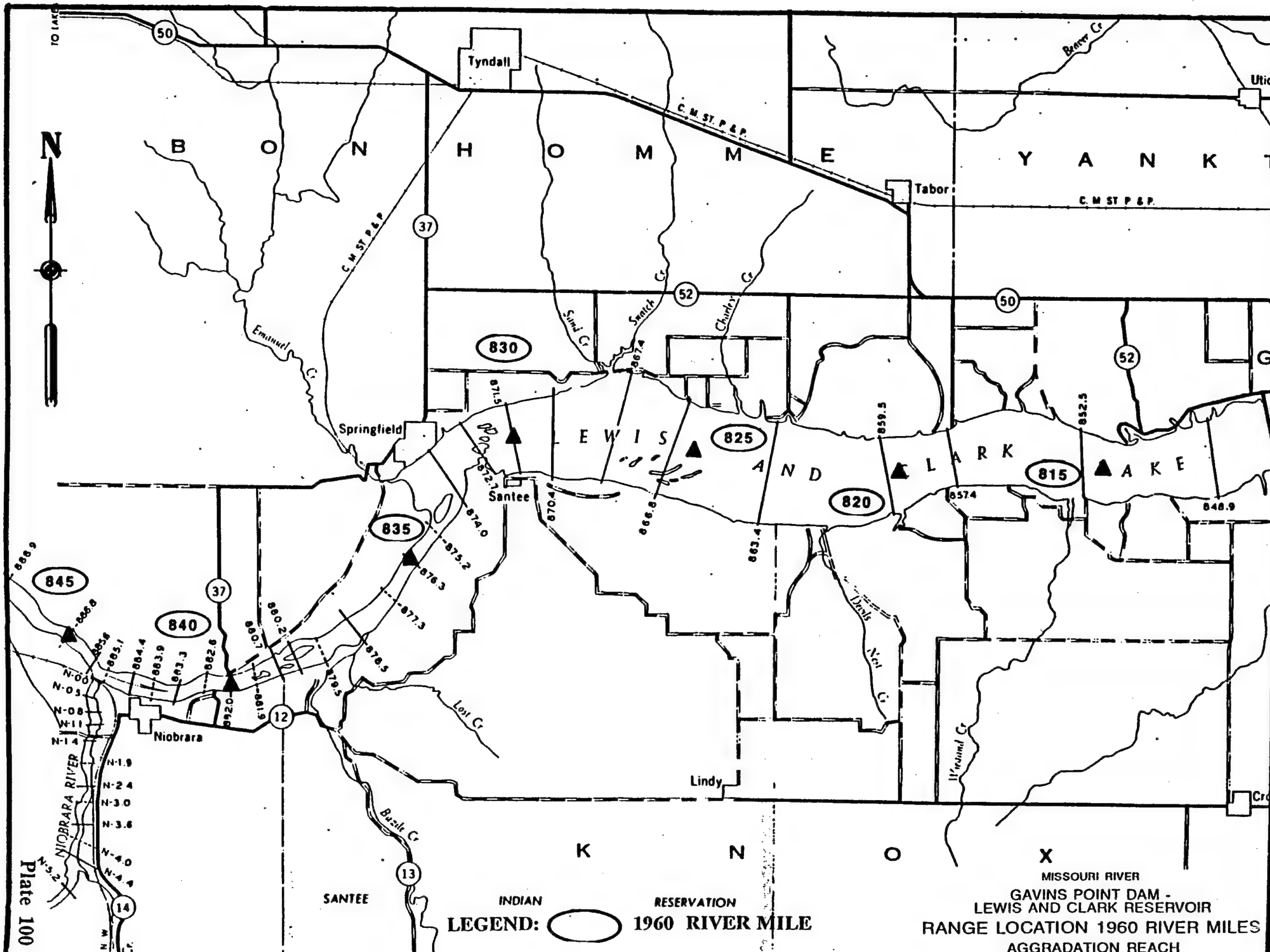

FORT RANDAL DEGRADATION REACH
CHANNEL CROSS-SECTION AREA PROFILE
1985
1967
1976
1952—1962
FT. RANDALL DAM
PONCA CREEK
NIOBRARA RIVER
NIOBRARA, NE.
840
845
850
855
860
865
870
875
880
1960 RIVER MILE
0
5000
10000
15000
20000
25000
AREA (SQUARE FEET)

Plate 97


FORT RANDALL DEGRADATION REACH
D50 GRAIN SIZE DISTRIBUTION
GRAIN SIZE (MM)
10
1
0.1
1960 RIVER MILE
840
845
850
855
860
865
870
875
880
NIOBRARA, NE.
NIOBRARA RIVER
PONCA CREEK
GREENWOOD, SD
FT. RANDALL DAM
1967
1985
1975
1956


FORT RANDALL DEGRADATION REACH
CUMULATIVE EROSION STUDY(R.M. 879.98-844.66)
CUMULATIVE EROSION (ACRE)
0
200
400
600
800
1000
1200
1400
1955
1960
1965
1970
1975
1980
1985
YEAR



MISSOURI RIVER
GAVINS POINT DAM -
LEWIS AND CLARK RESERVOIR
RANGE LOCATION 1960 RIVER MILES
AGGRADATION REACH

Plate 100

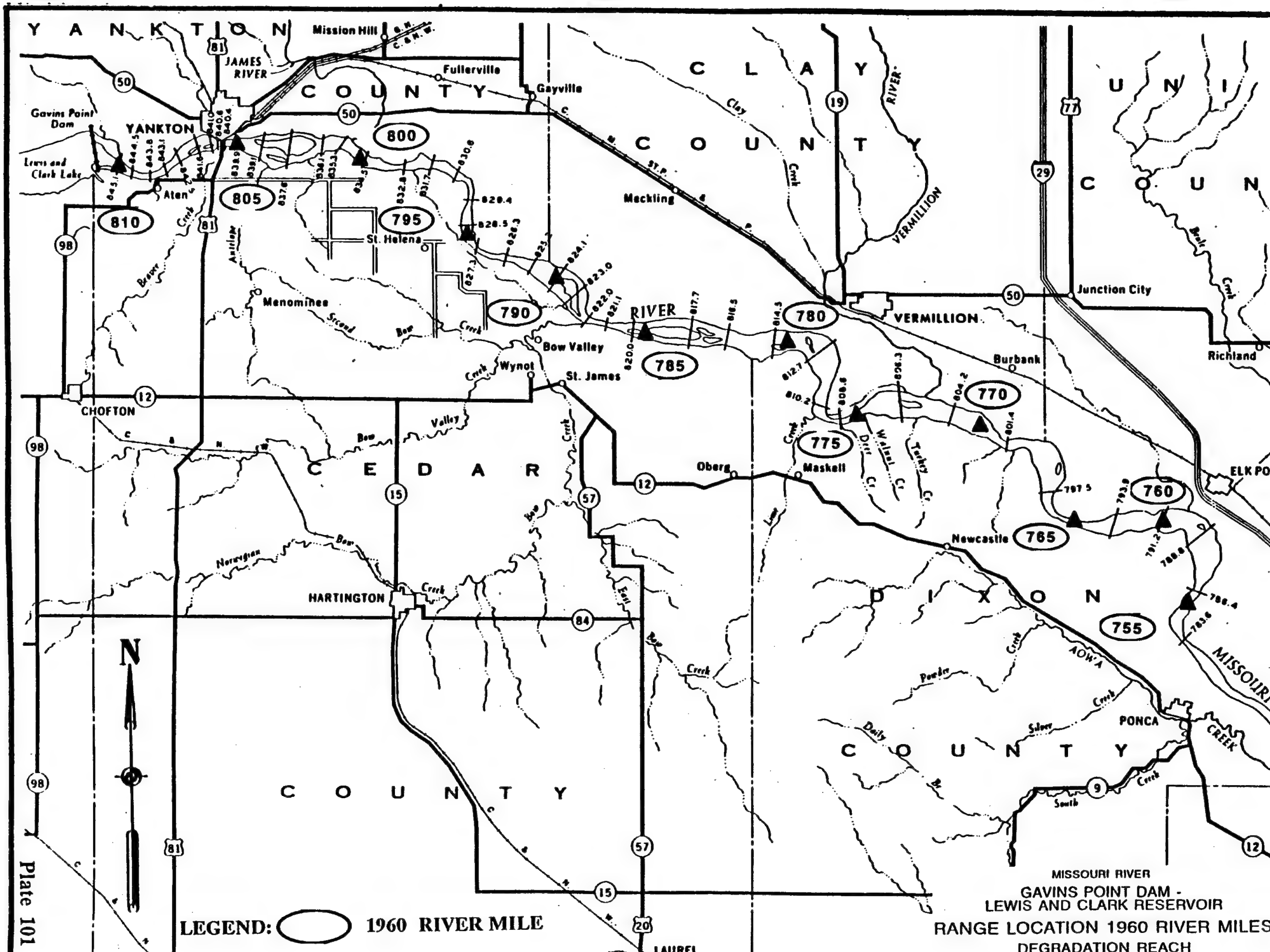
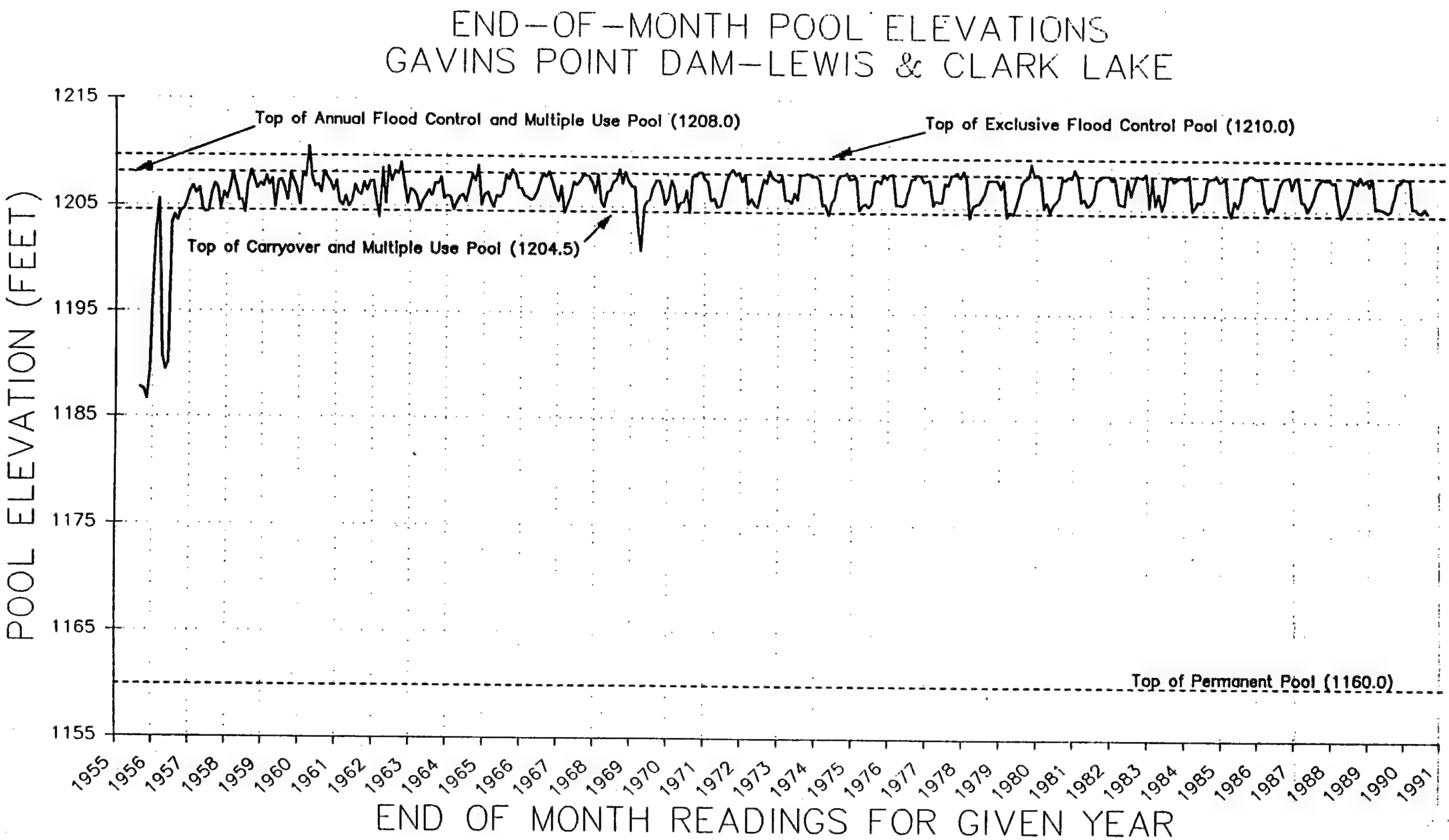
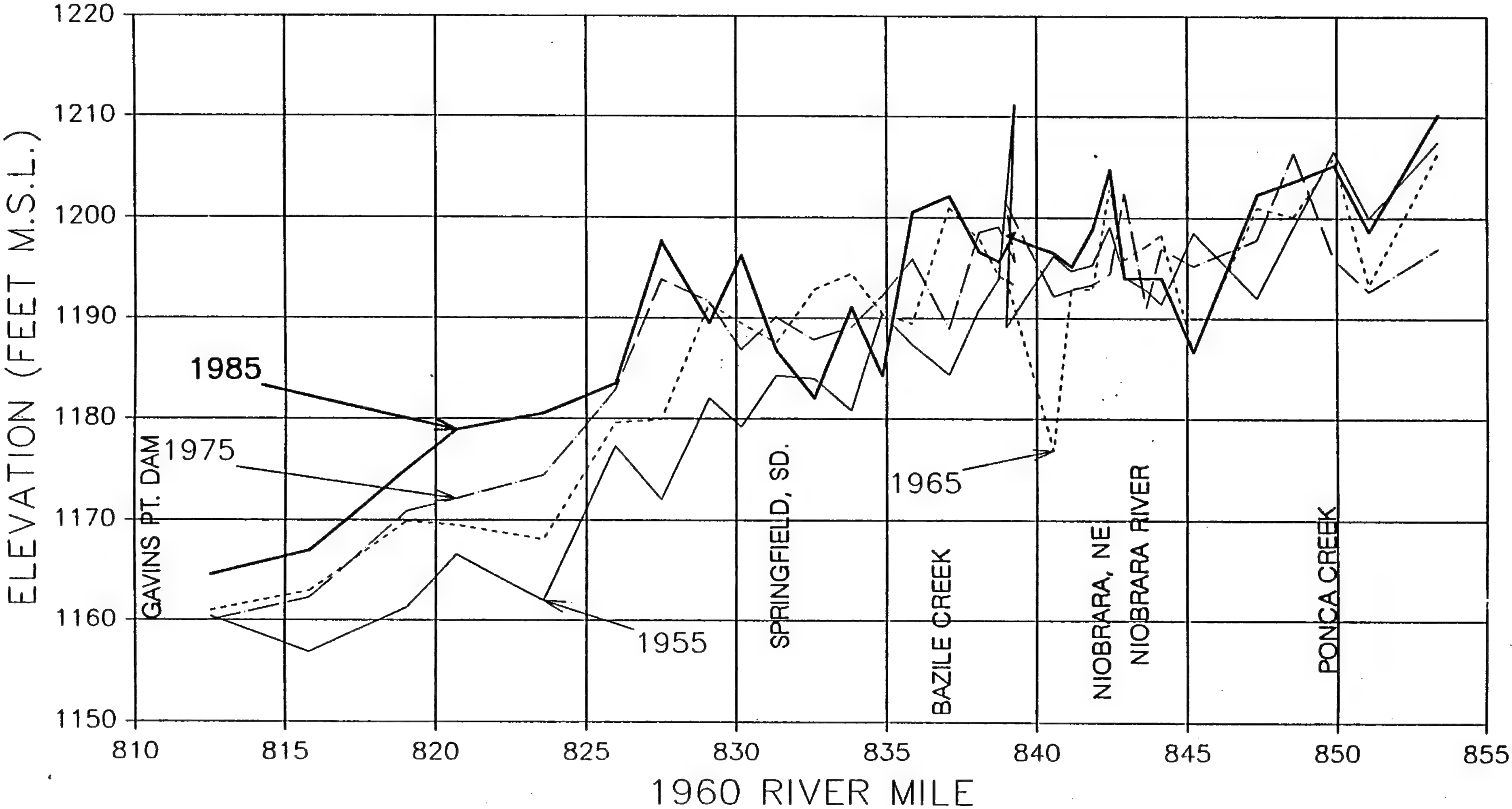

YANKTON
COUNTY
CLAY
COUNTY
UNION
COUNTY
CEDAR
COUNTY
DIXON
COUNTY
Mission Hill
Fullerville
Gayville
JAMES RIVER
YANKTON
Gavins Point Dam
Lewis and Clark Lake
Aten
St. Helena
Menominee
Meckling
VERMILLION
Junction City
Richland
Burbank
ELK POI
Bow Valley
Wynot
St. James
CHOFTON
HARTINGTON
Oberg
Maskell
Newcastle
PONCA
LAUREL
RIVER
MISSOURI
VERMILLION
Clay Creek
Beaver Creek
Antelope
Second Bow Creek
Bow Creek
Valley
Norwegian
East Bow Creek
Turkey Cr
Walnut Cr
Deer Cr
Lime Creek
Powder Creek
Silver Creek
Daily Br
South Creek
AOWA
CREEK
Brule Creek
810
805
800
795
790
785
780
775
770
765
760
755
N
LEGEND:
1960 RIVER MILE
MISSOURI RIVER
GAVINS POINT DAM -
LEWIS AND CLARK RESERVOIR
RANGE LOCATION 1960 RIVER MILES
DEGRADATION REACH

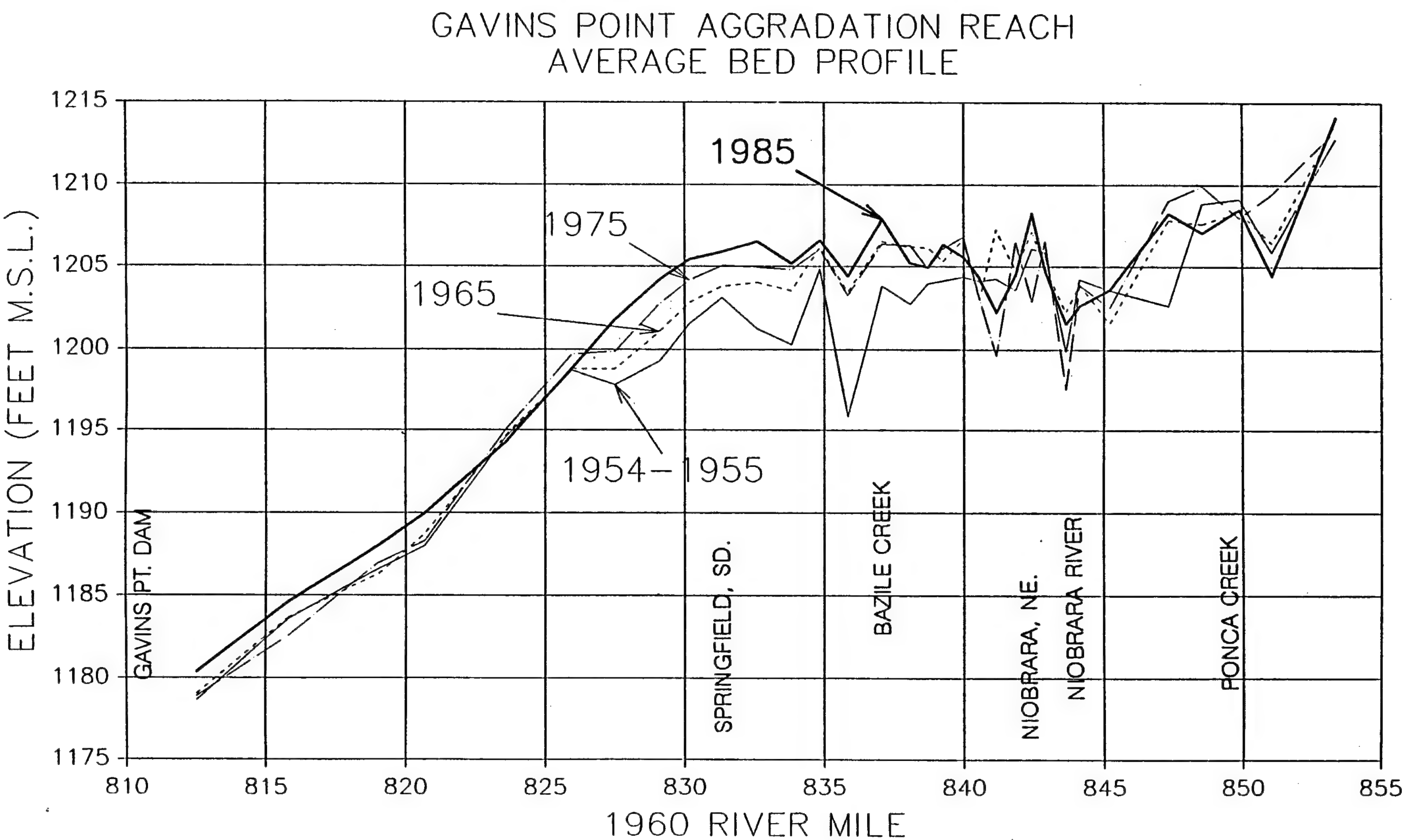
Plate 101

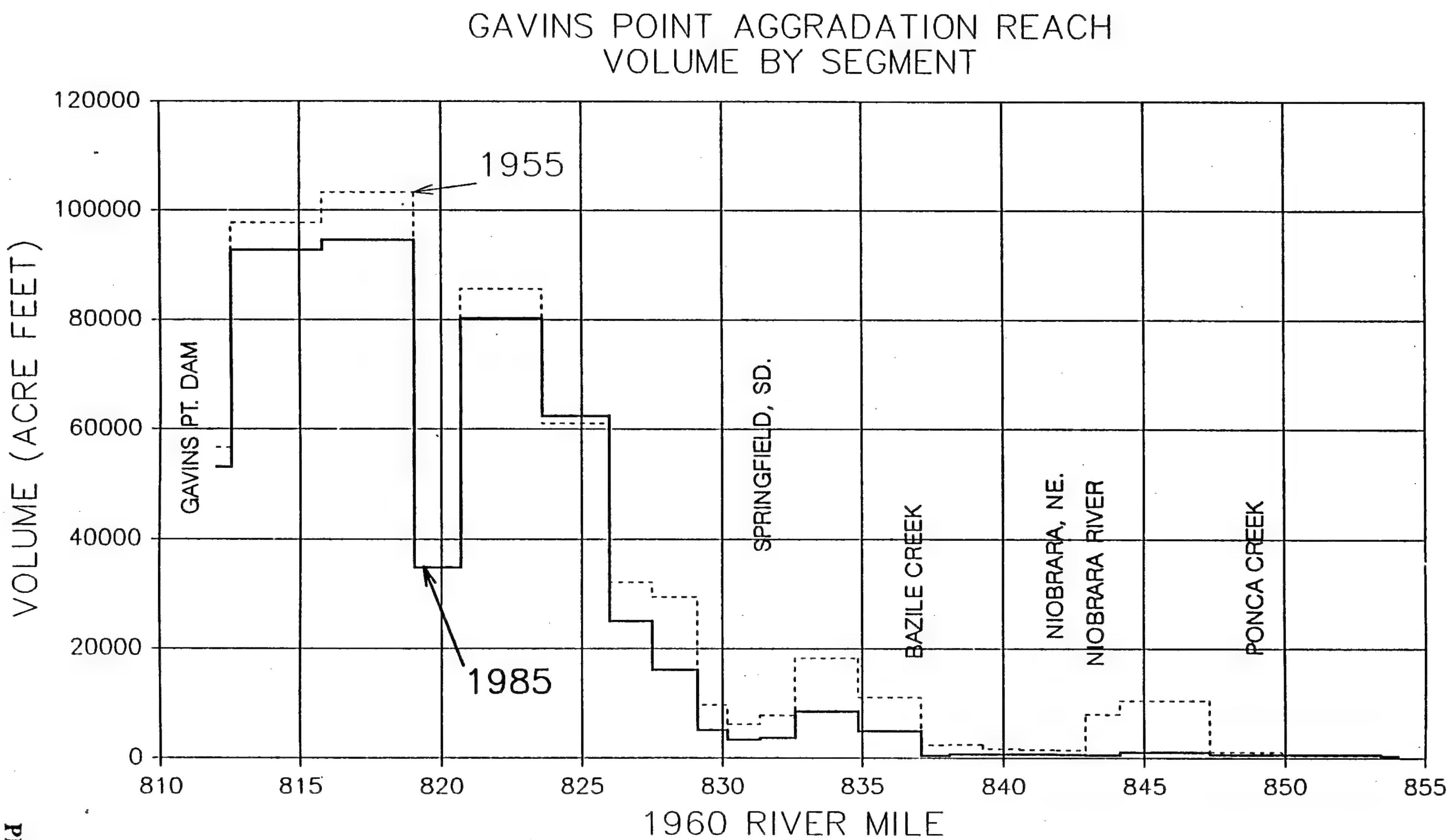


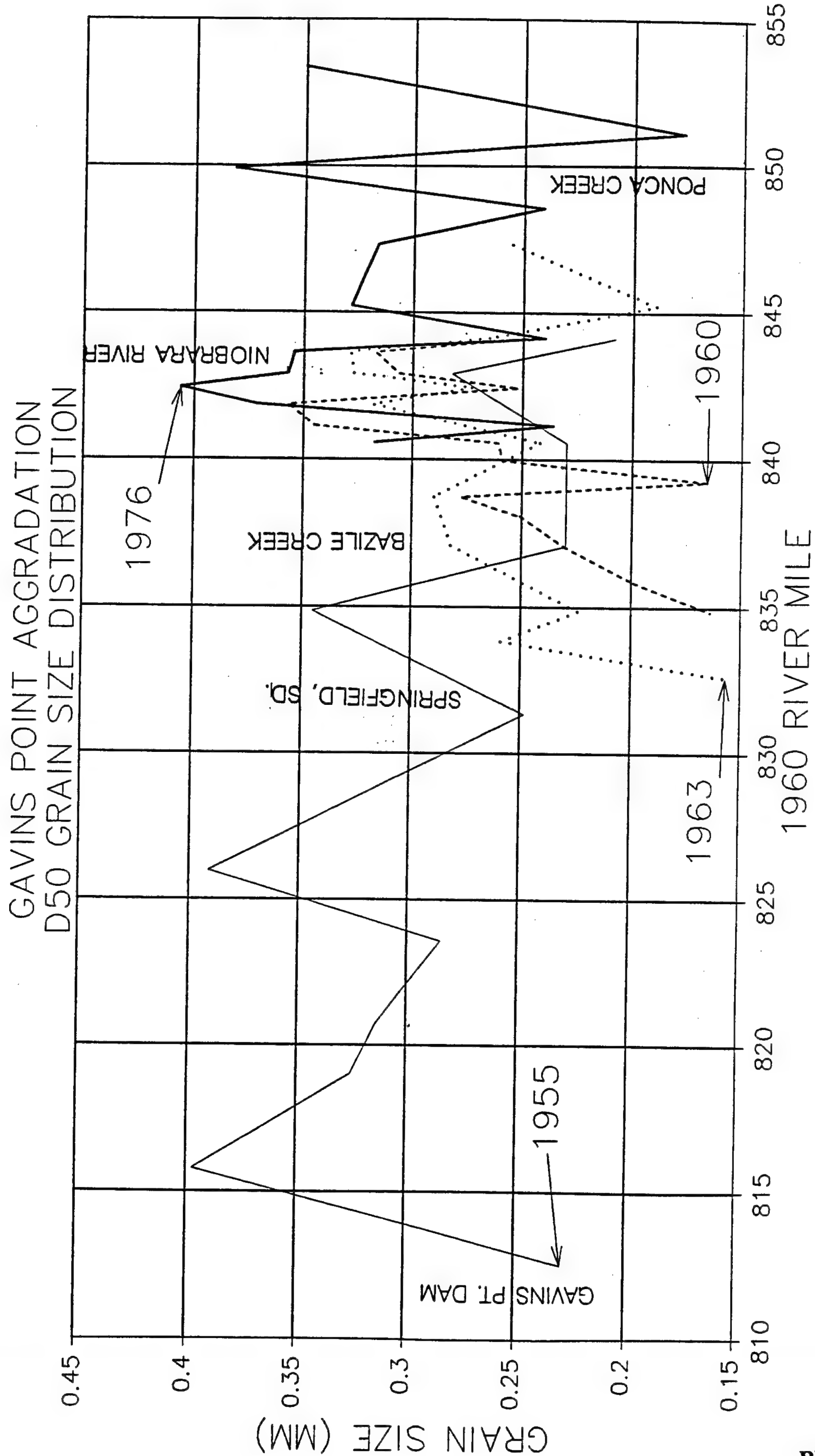
END—OF—MONTH POOL ELEVATIONS
GAVINS POINT DAM—LEWIS & CLARK LAKE
POOL ELEVATION (FEET)
1215
1205
1195
1185
1175
1165
1155
Top of Annual Flood Control and Multiple Use Pool (1208.0)
Top of Exclusive Flood Control Pool (1210.0)
Top of Carryover and Multiple Use Pool (1204.5)
Top of Permanent Pool (1160.0)
1955 1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991
END OF MONTH READINGS FOR GIVEN YEAR

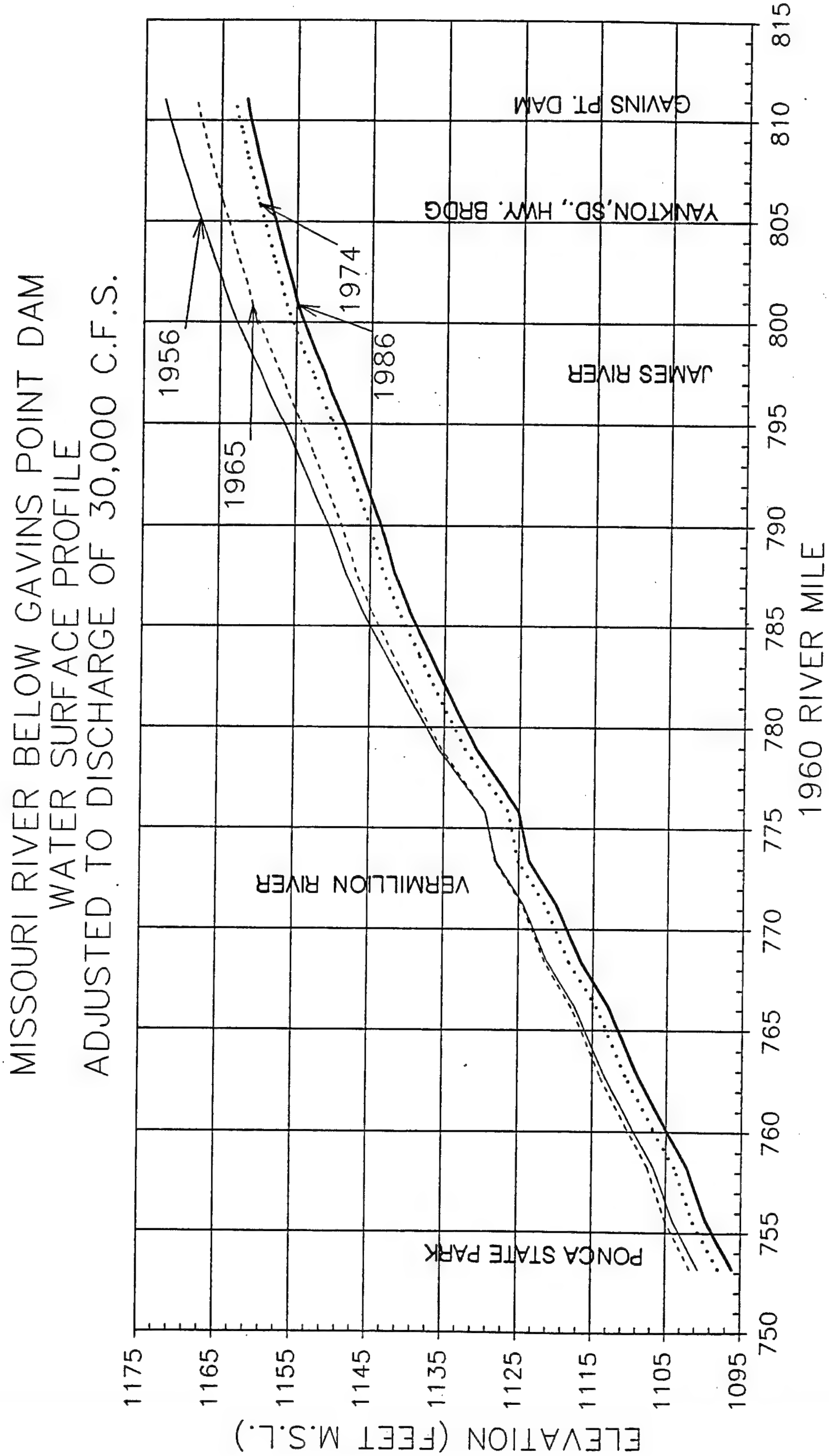
GAVINS POINT AGGRADATION REACH
THALWEG PROFILE




GAVINS POINT AGGRADATION REACH
AVERAGE BED PROFILE
ELEVATION (FEET M.S.L.)
1960 RIVER MILE
1215
1210
1205
1200
1195
1190
1185
1180
1175
810
815
820
825
830
835
840
845
850
855
1985
1975
1965
1954–1955
GAVINS PT. DAM
SPRINGFIELD, SD.
BAZILE CREEK
NIOBRARA, NE.
NIOBRARA RIVER
PONCA CREEK

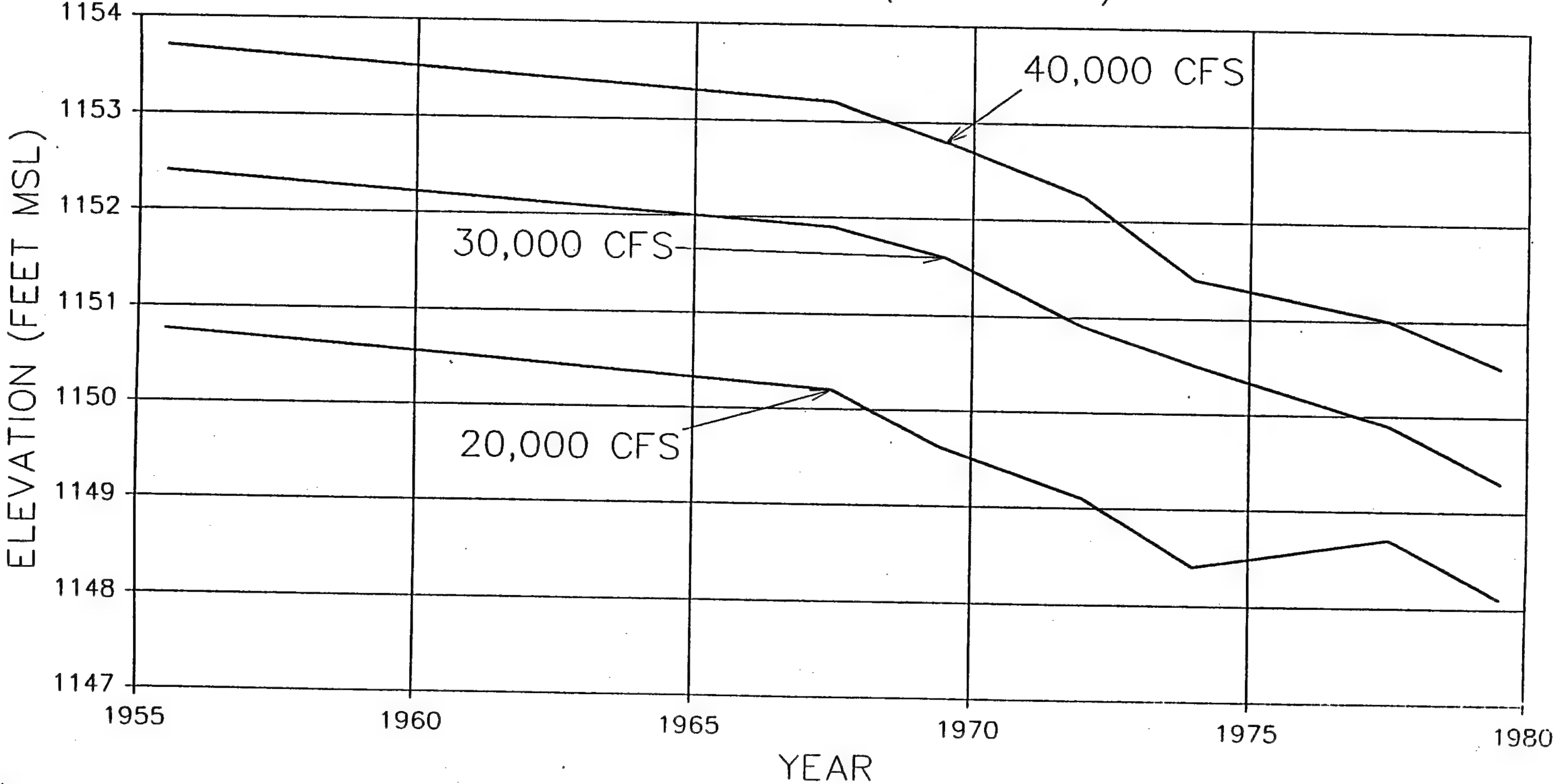

GAVINS POINT AGGRADATION REACH
VOLUME BY SEGMENT
VOLUME (ACRE FEET)
1960 RIVER MILE
1955
1985
GAVINS PT. DAM
SPRINGFIELD, SD.
BAZILE CREEK
NIOBRARA, NE.
NIOBRARA RIVER
PONCA CREEK
0
20000
40000
60000
80000
100000
120000
810
815
820
825
830
835
840
845
850
855


GAVINS POINT AGGRADATION
D50 GRAIN SIZE DISTRIBUTION
GRAIN SIZE (MM)
1960 RIVER MILE
0.45
0.4
0.35
0.3
0.25
0.2
0.15
810
815
820
825
830
835
840
845
850
855
GAVINS PT. DAM
SPRINGFIELD, SD.
BAZILE CREEK
NIOBRARA RIVER
PONCA CREEK
1955
1963
1976
1960

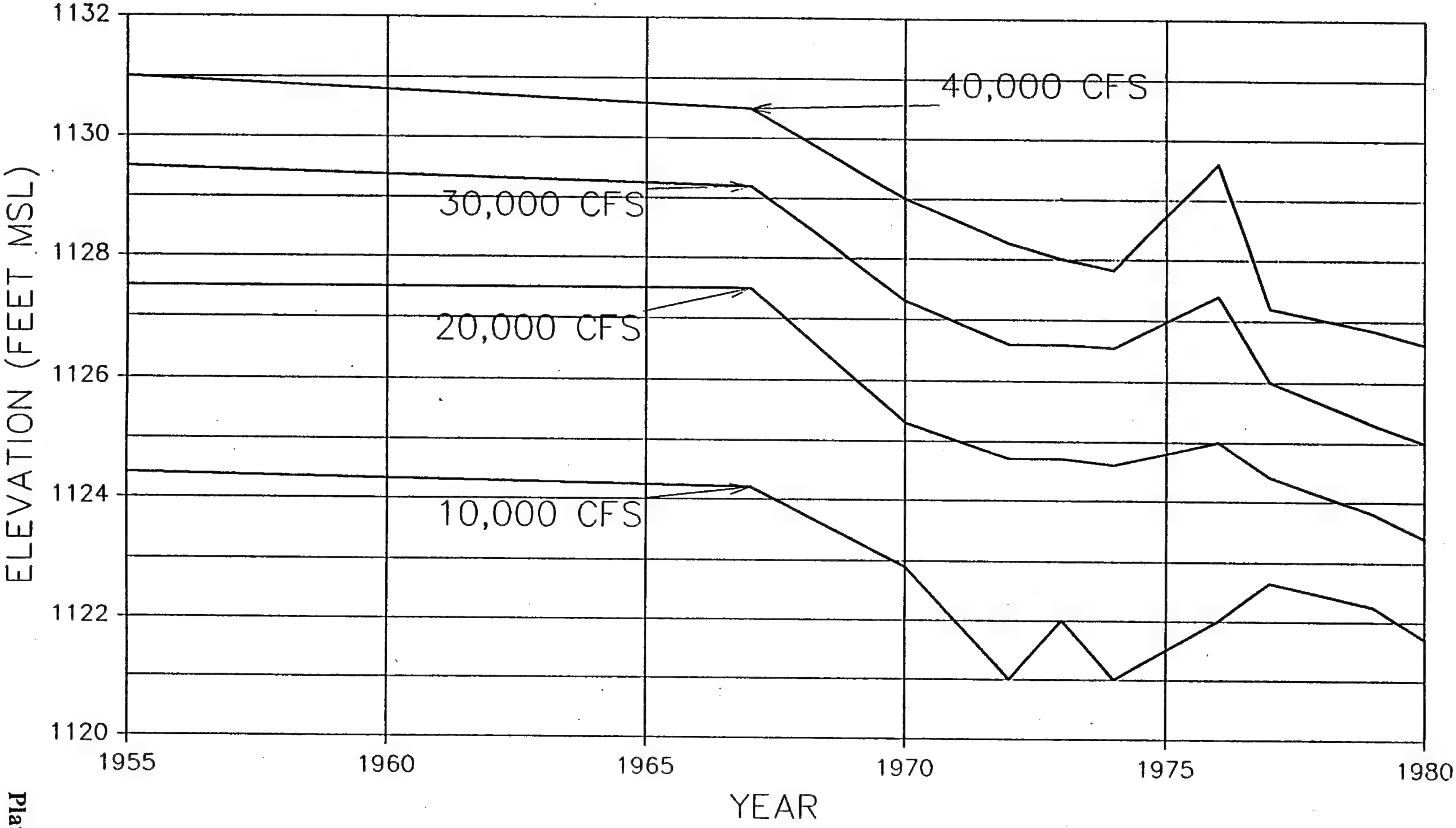


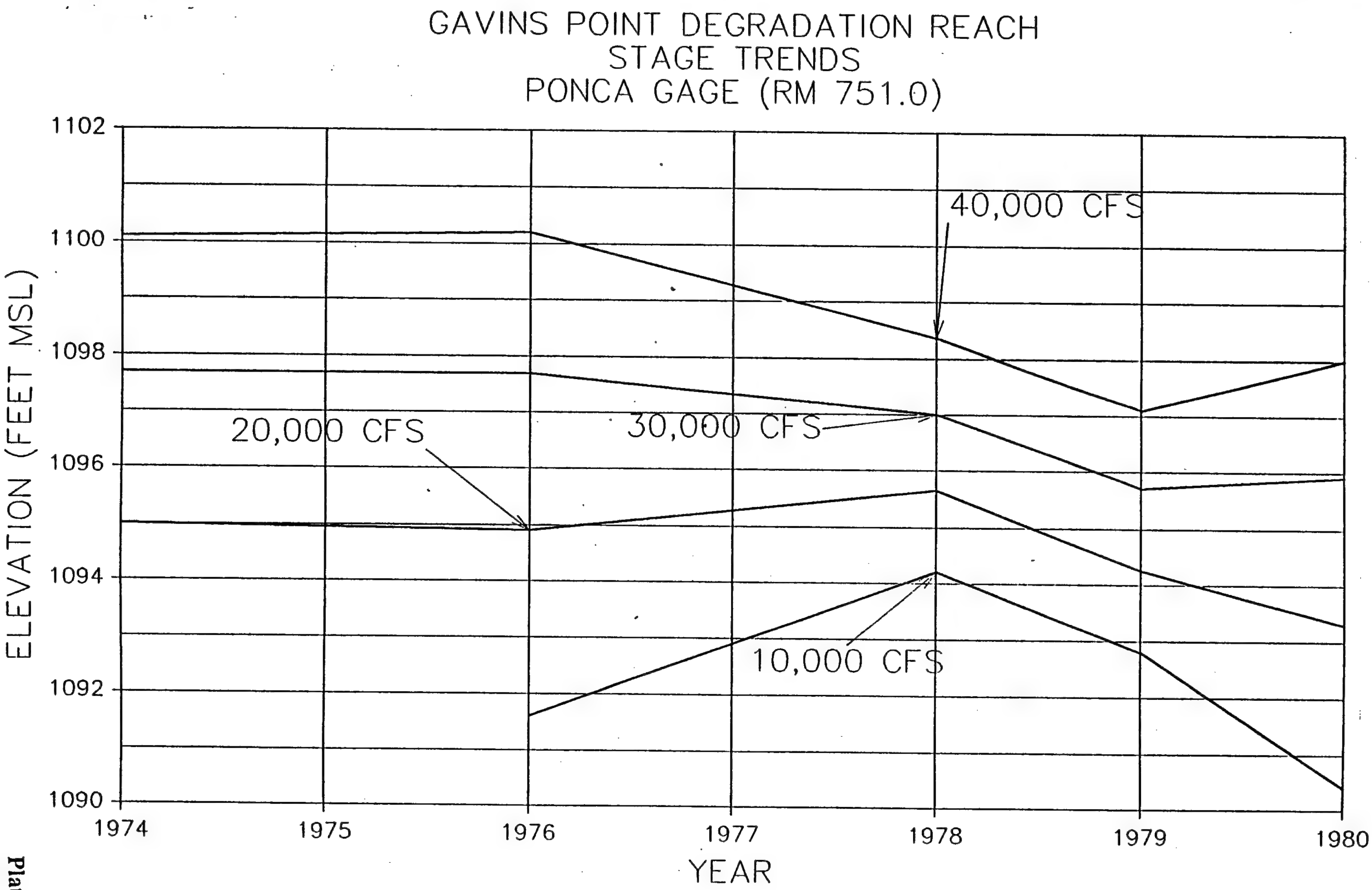
MISSOURI RIVER BELOW GAVINS POINT DAM
WATER SURFACE PROFILE
ADJUSTED TO DISCHARGE OF 30,000 C.F.S.
GAVINS PT. DAM
YANKTON,SD., HWY. BRDG
JAMES RIVER
VERMILLION RIVER
PONCA STATE PARK
1956
1965
1974
1986
ELEVATION (FEET M.S.L.)
1175
1165
1155
1145
1135
1125
1115
1105
1095
1960 RIVER MILE
750
755
760
765
770
775
780
785
790
795
800
805
810
815

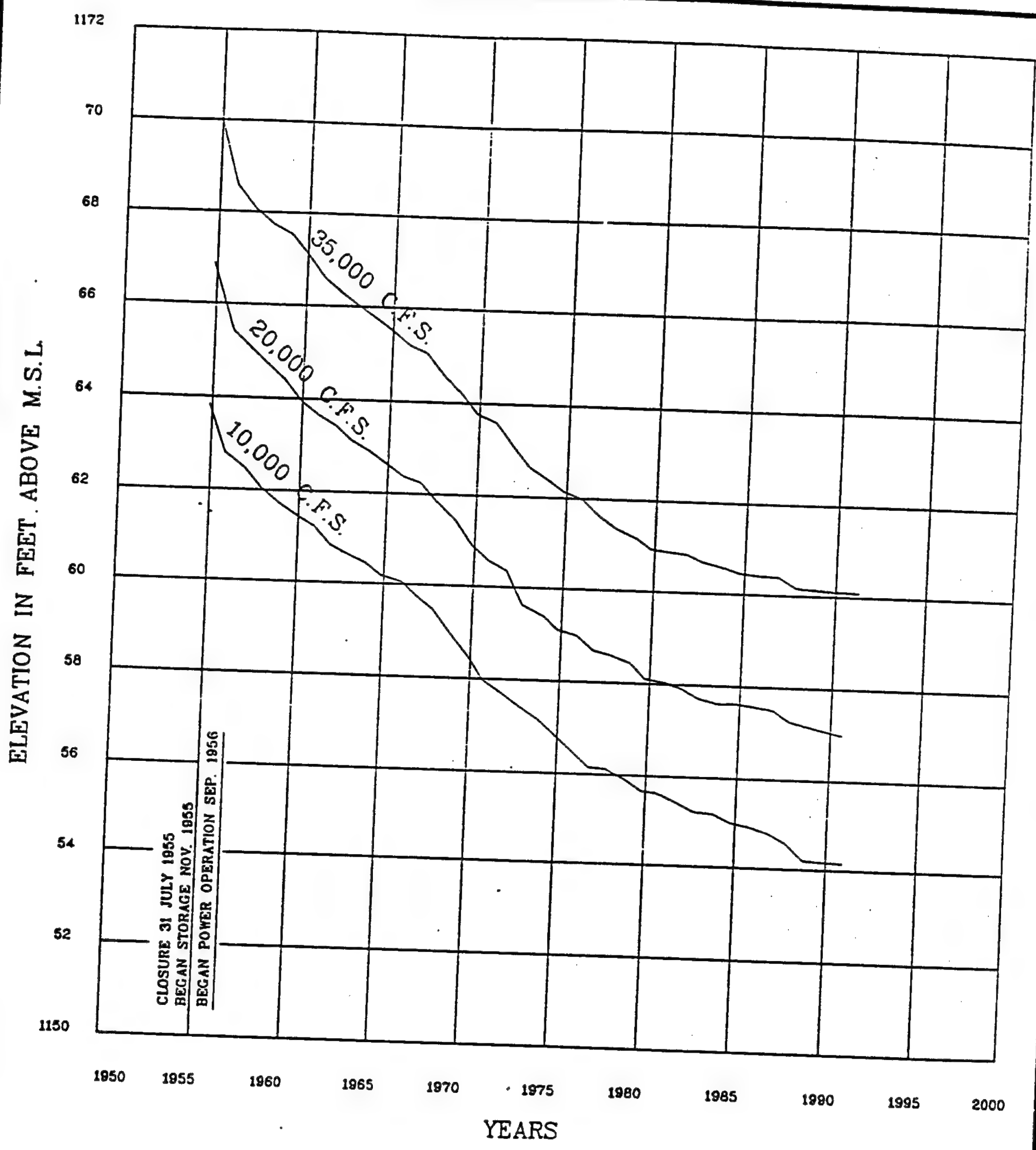
GAVINS POINT DEGRADATION REACH
STAGE TRENDS
GAYVILLE GAGE (RM 796.00)



GAVINS POINT DEGRADATION REACH
STAGE TRENDS
MASKELL GAGE (RM 775.8)

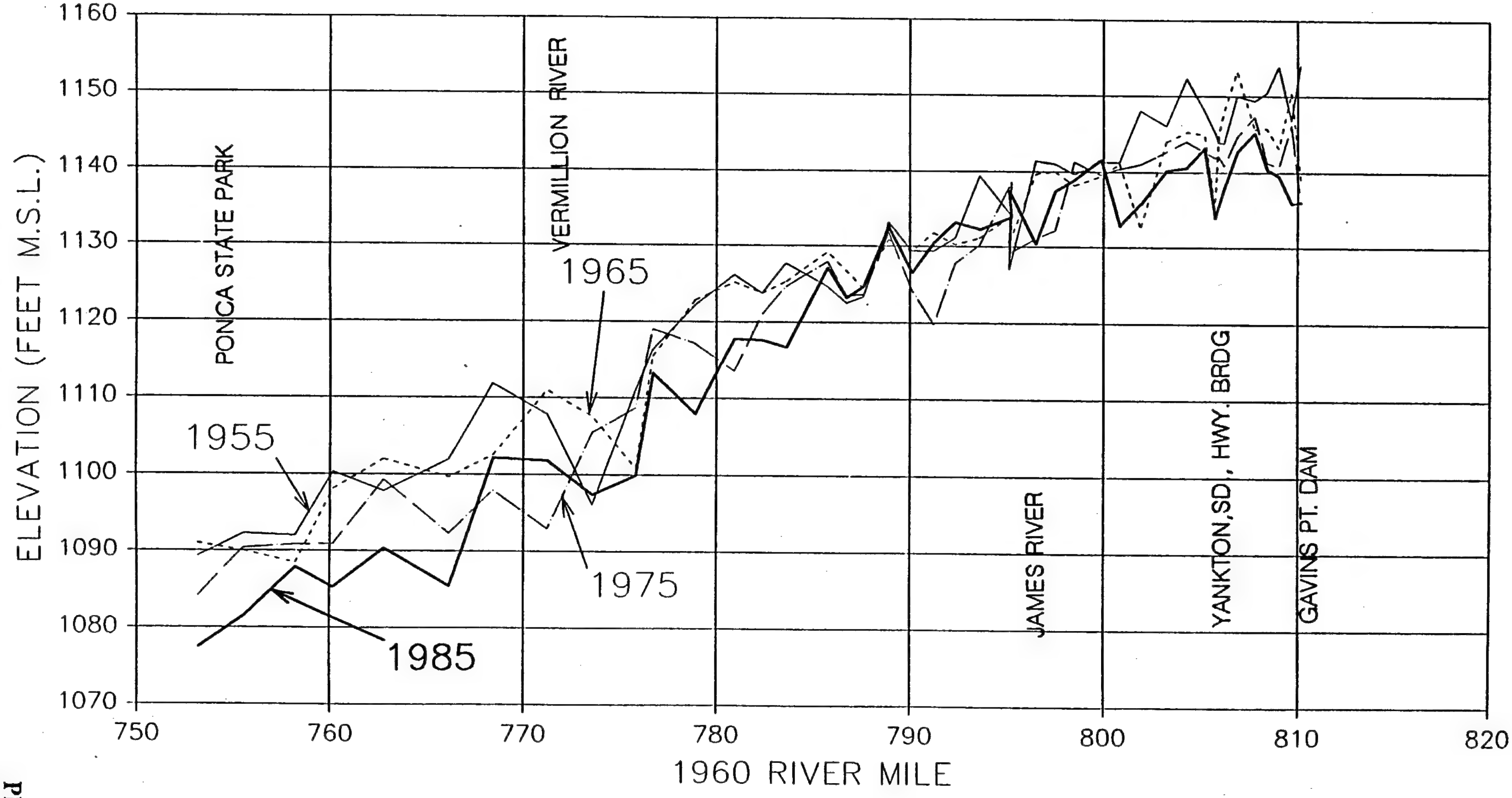


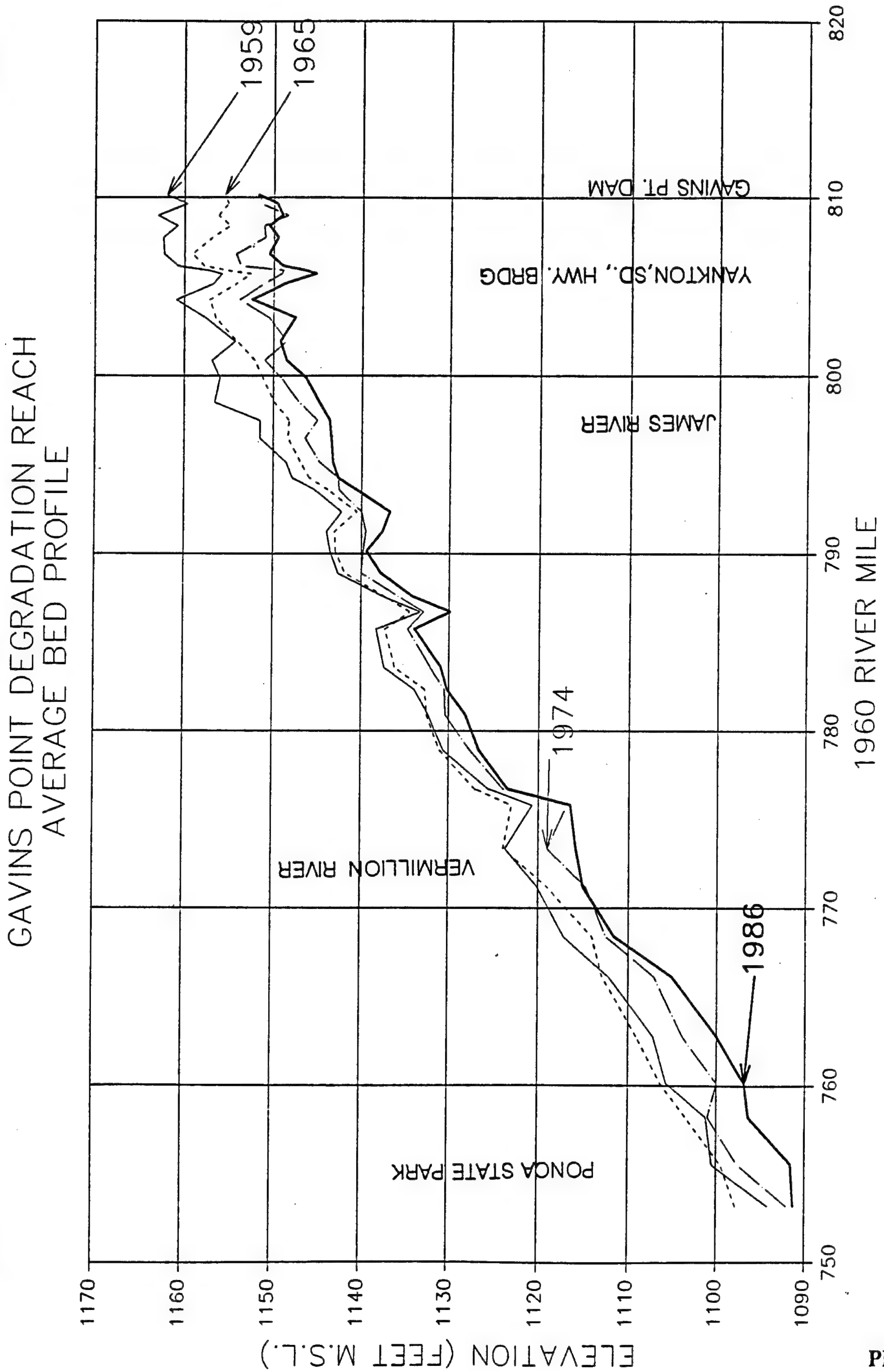

GAVINS POINT DEGRADATION REACH
STAGE TRENDS
PONCA GAGE (RM 751.0)
ELEVATION (FEET MSL)
1102
1100
1098
1096
1094
1092
1090
1974
1975
1976
1977
1978
1979
1980
YEAR
40,000 CFS
30,000 CFS
20,000 CFS
10,000 CFS



MISSOURI RIVER
GAVINS POINT PROJECT
TAILWATER TRENDS
U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA
MARCH 1992

GAVINS POINT DEGRADATION REACH
THALWEG PROFILE





GAVINS POINT DEGRADATION REACH
AVERAGE BED PROFILE
1959
1965
1974
1986
GAVINS PT. DAM
YANKTON,SD., HWY. BRDG
JAMES RIVER
VERMILLION RIVER
PONCA STATE PARK
750
760
770
780
790
800
810
820
1960 RIVER MILE
1170
1160
1150
1140
1130
1120
1110
1100
1090
ELEVATION (FEET M.S.L.)

Plate 113

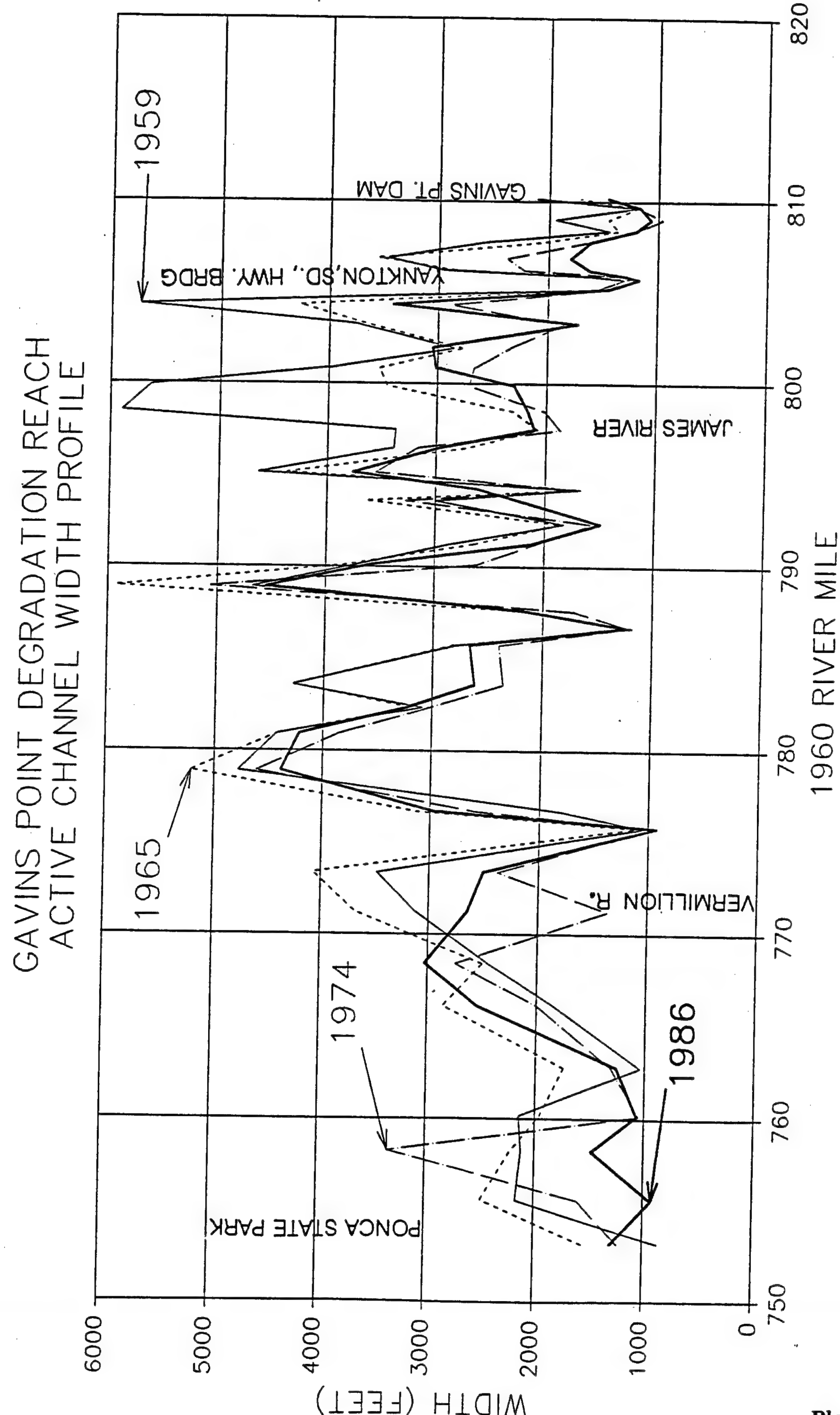
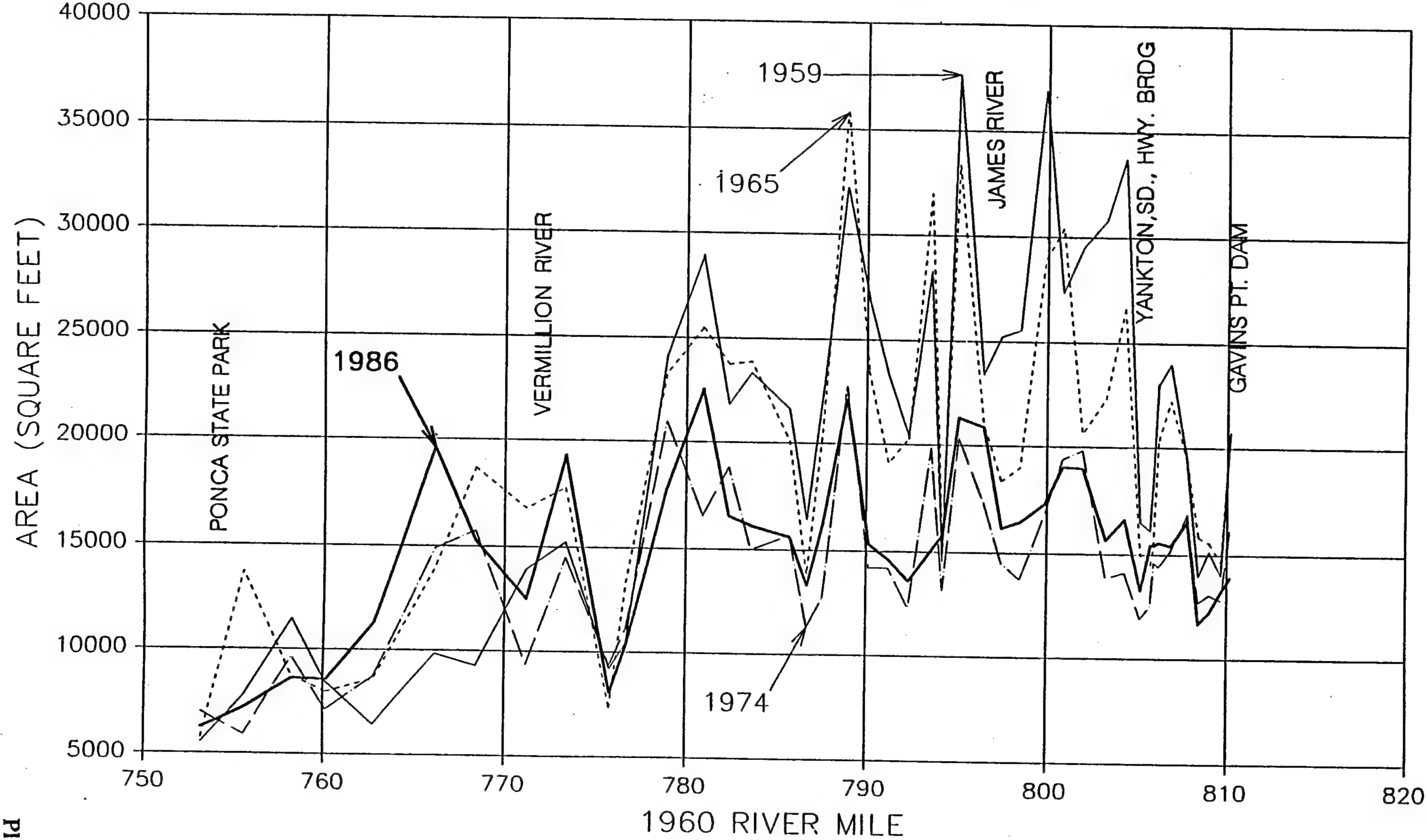
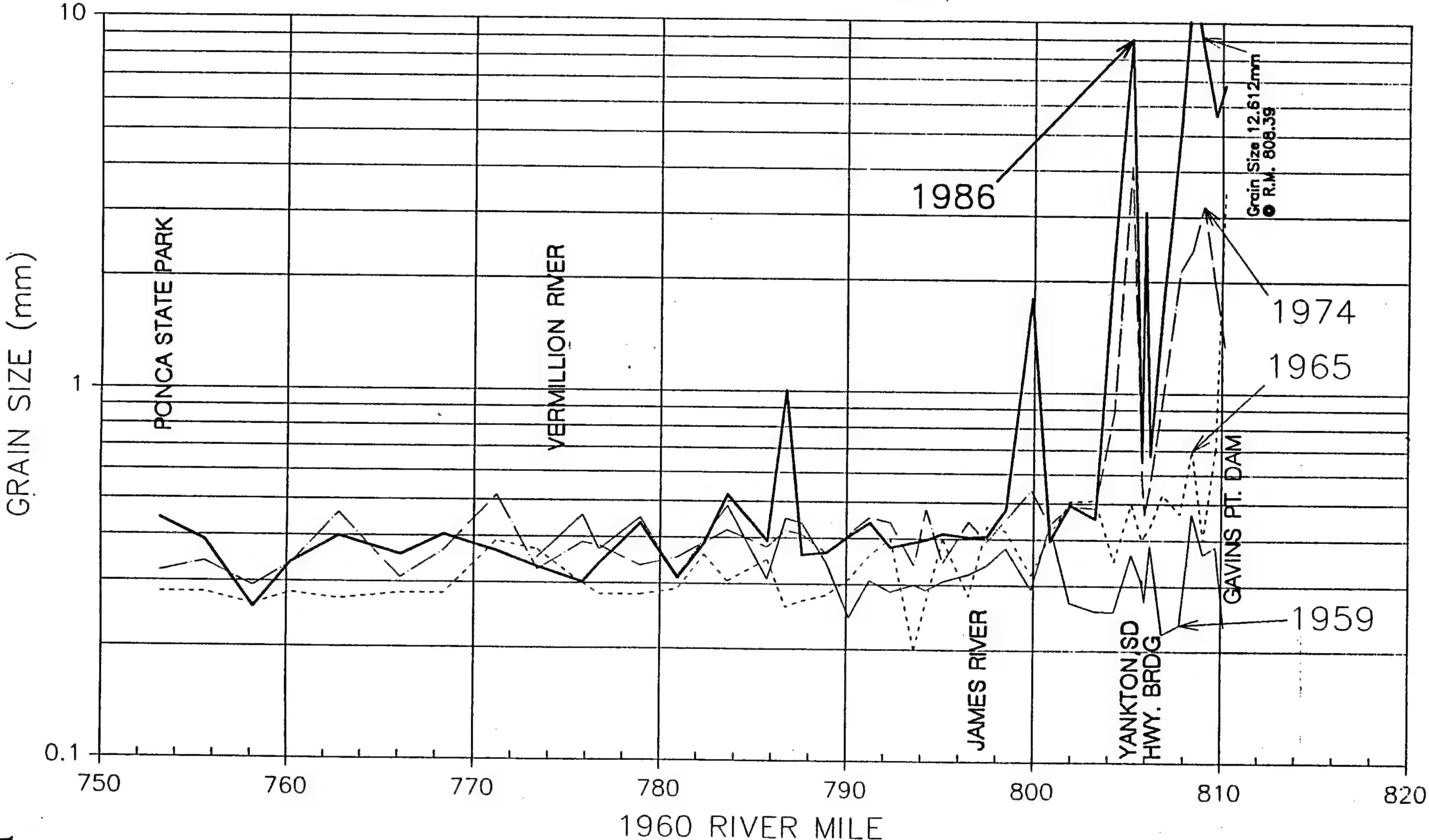

GAVINS POINT DEGRADATION REACH
ACTIVE CHANNEL WIDTH PROFILE
WIDTH (FEET)
6000
5000
4000
3000
2000
1000
0
750
760
770
780
790
800
810
820
1960 RIVER MILE
1959
1965
1974
1986
GAVINS PT. DAM
YANKTON, SD., HWY. BRDG
JAMES RIVER
VERMILLION R.
PONCA STATE PARK

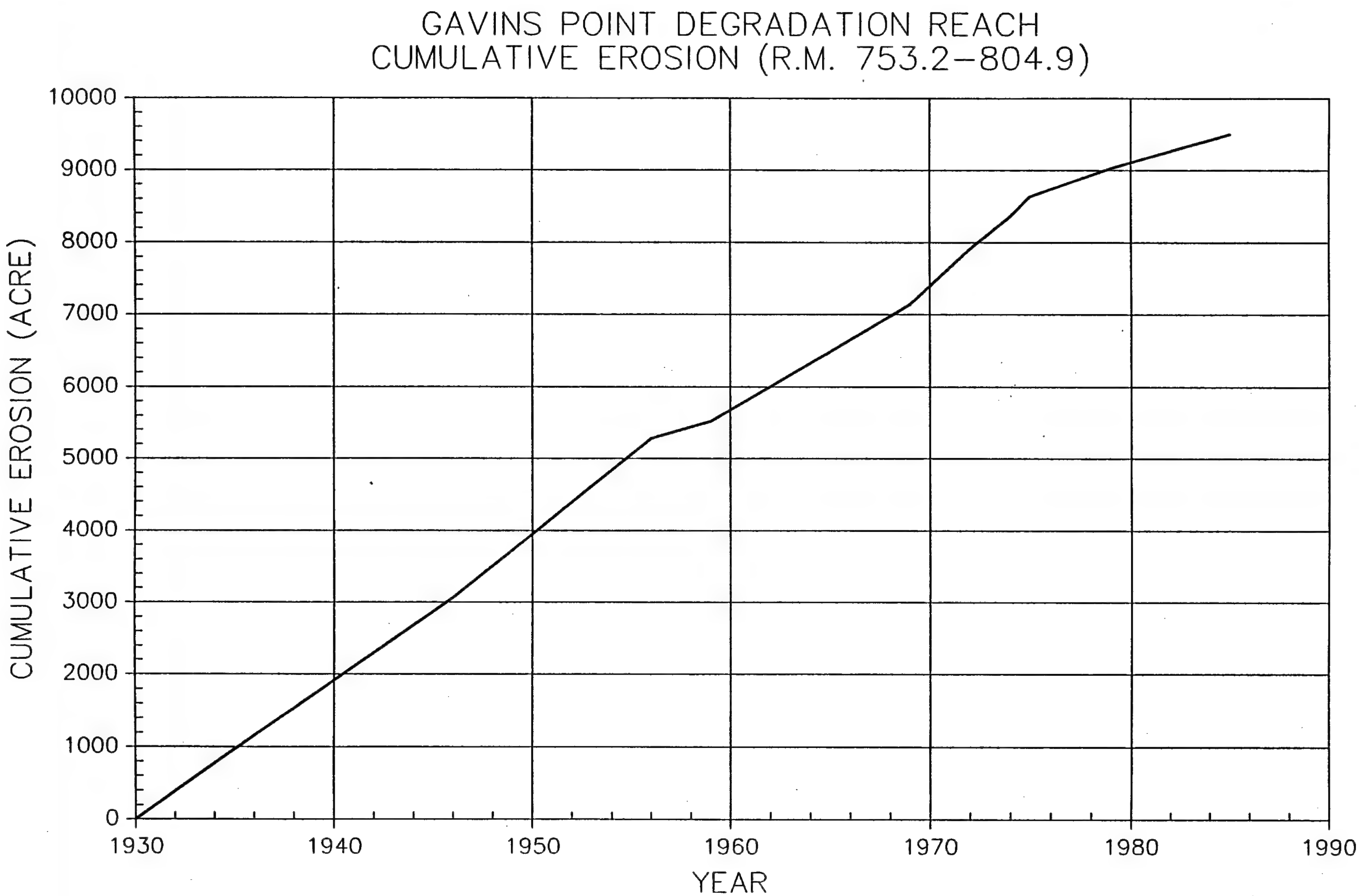
Plate 114

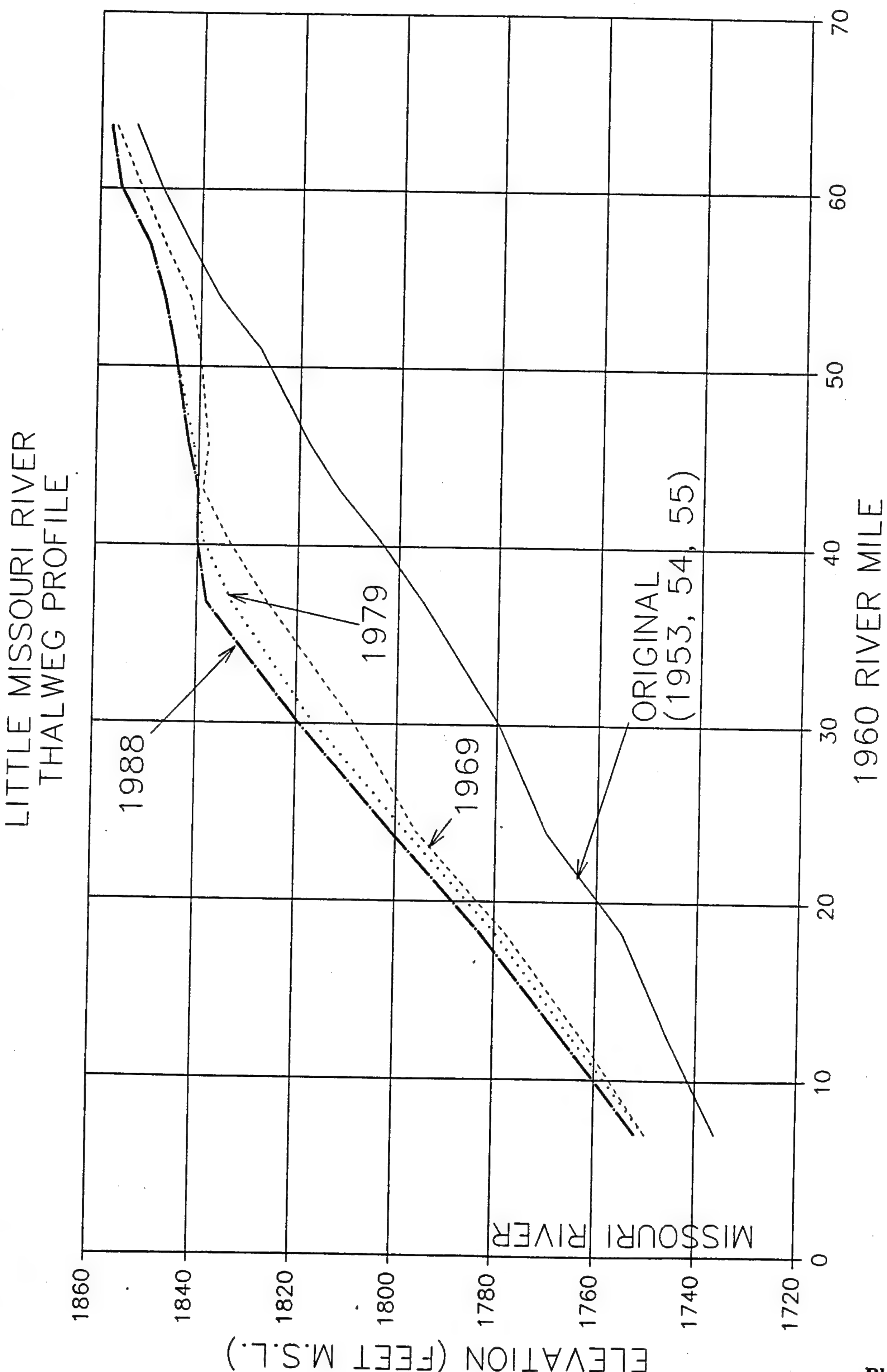
GAVINS POINT DEGRADATION REACH
CHANNEL CROSS-SECTION AREA PROFILE



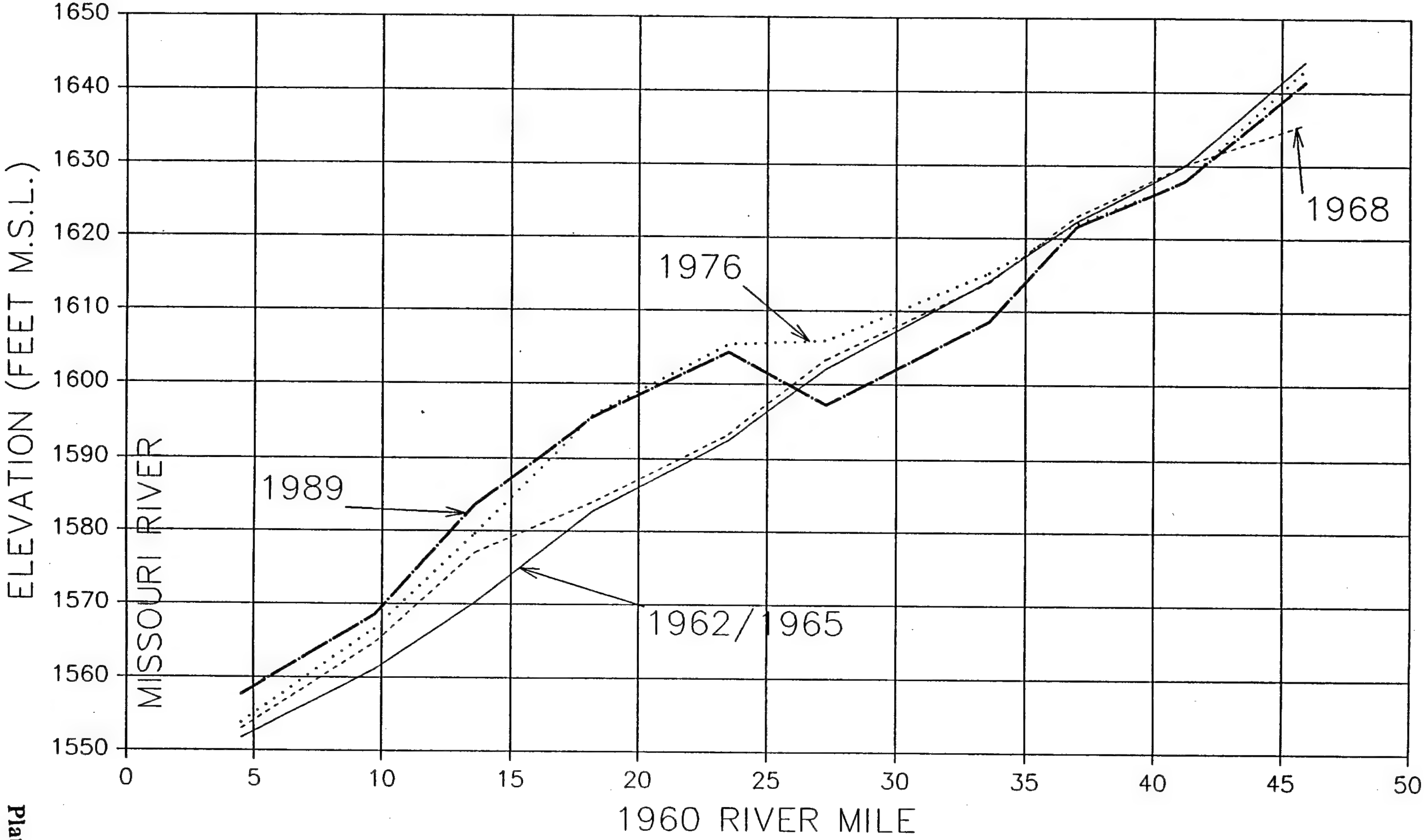
GAVINS POINT DEGRADATION REACH
D50 GRAIN SIZE DISTRIBUTION



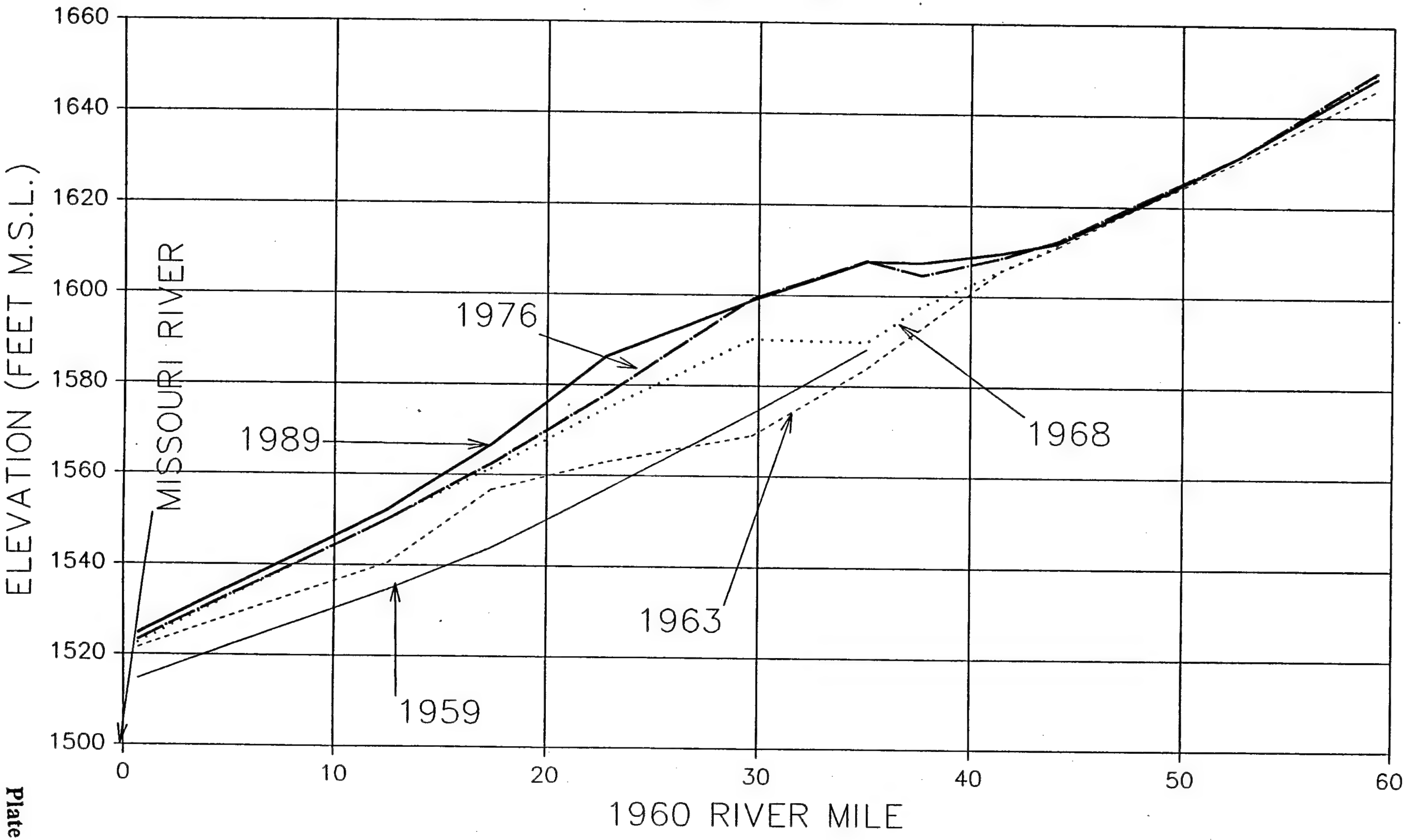

GAVINS POINT DEGRADATION REACH
CUMULATIVE EROSION (R.M. 753.2–804.9)
CUMULATIVE EROSION (ACRE)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1930
1940
1950
1960
1970
1980
1990
YEAR

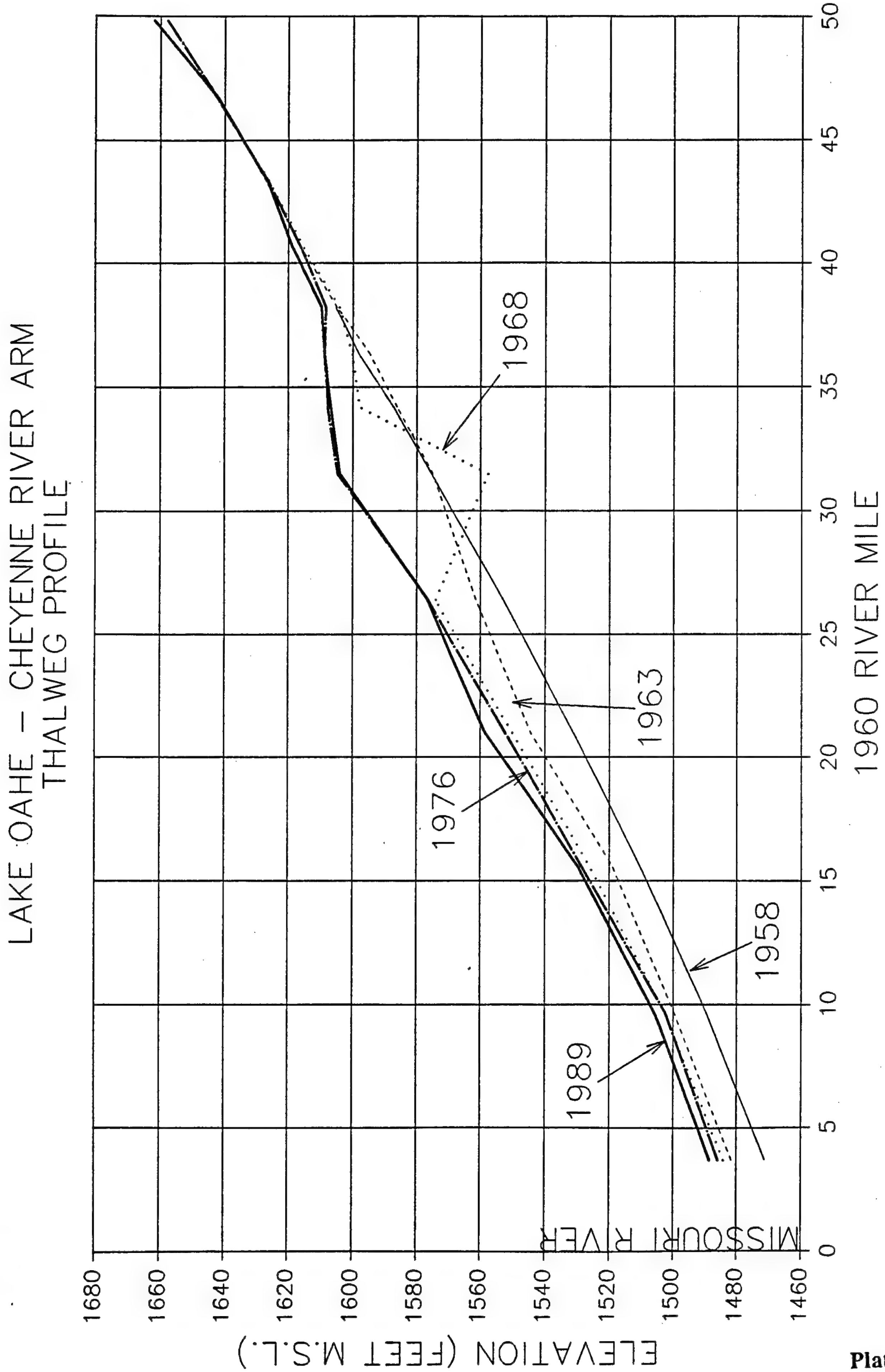

LITTLE MISSOURI RIVER
THALWEG PROFILE
1988
1979
1969
ORIGINAL
(1953, 54, 55)
MISSOURI RIVER
ELEVATION (FEET M.S.L.)
1960 RIVER MILE
1860
1840
1820
1800
1780
1760
1740
1720
0
10
20
30
40
50
60
70

LAKE OAHE — GRAND RIVER ARM
THALWEG PROFILE

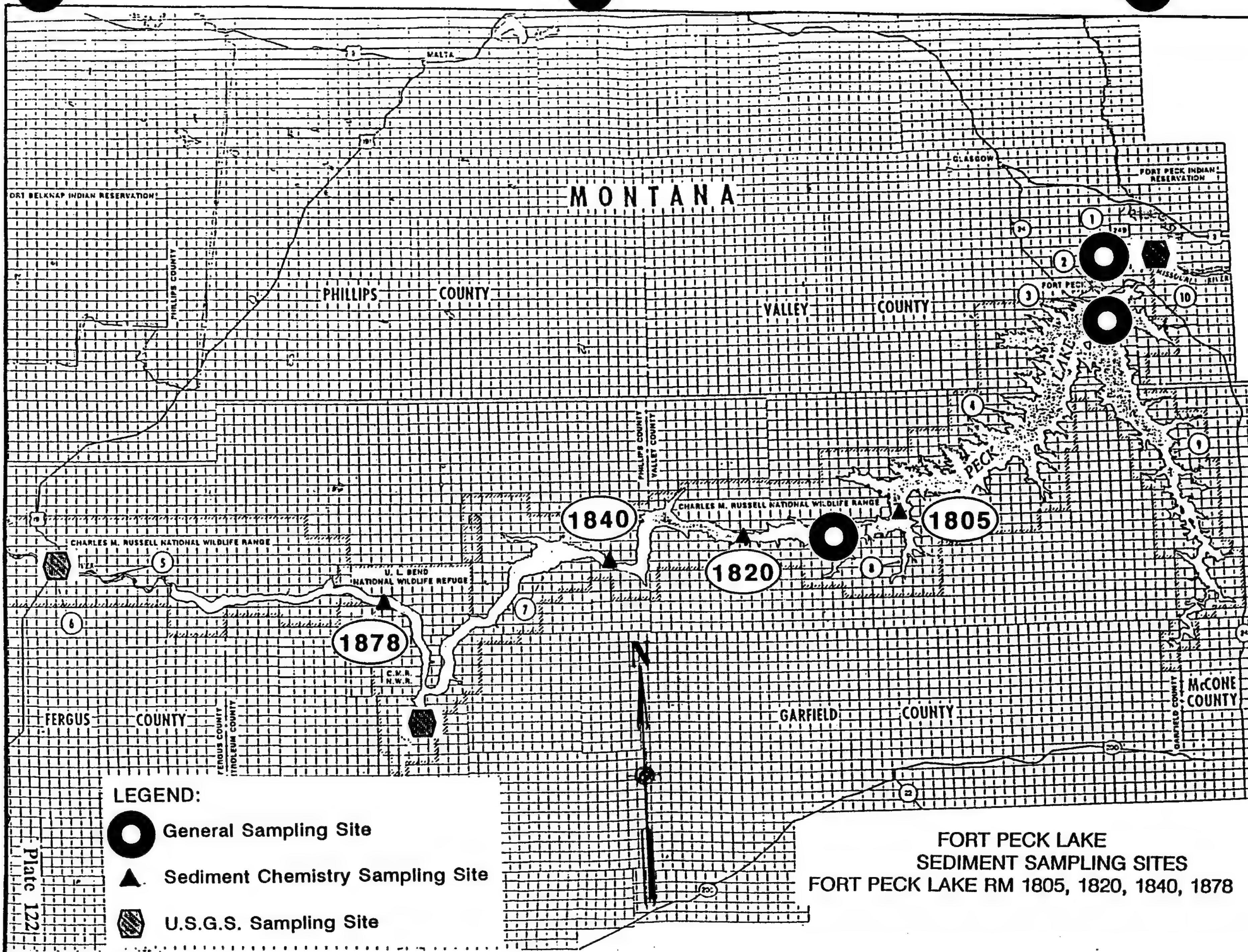


LAKE OAHE – MOREAU RIVER ARM
THALWEG PROFILE

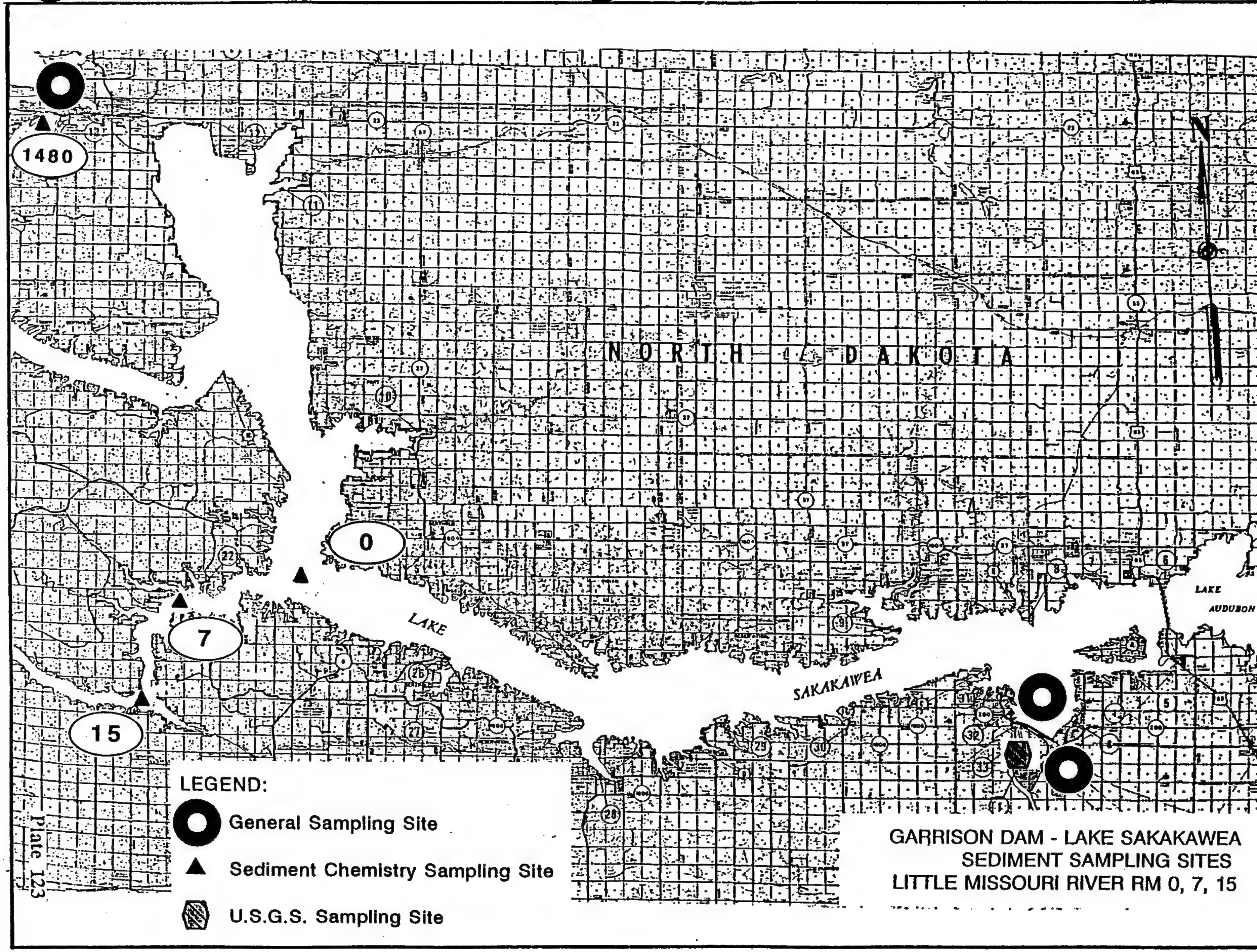




LAKE OAHE – CHEYENNE RIVER ARM
THALWEG PROFILE
1968
1963
1976
1958
1989
MISSOURI RIVER
1960 RIVER MILE
0
5
10
15
20
25
30
35
40
45
50
ELEVATION (FEET M.S.L.)
1460
1480
1500
1520
1540
1560
1580
1600
1620
1640
1660
1680

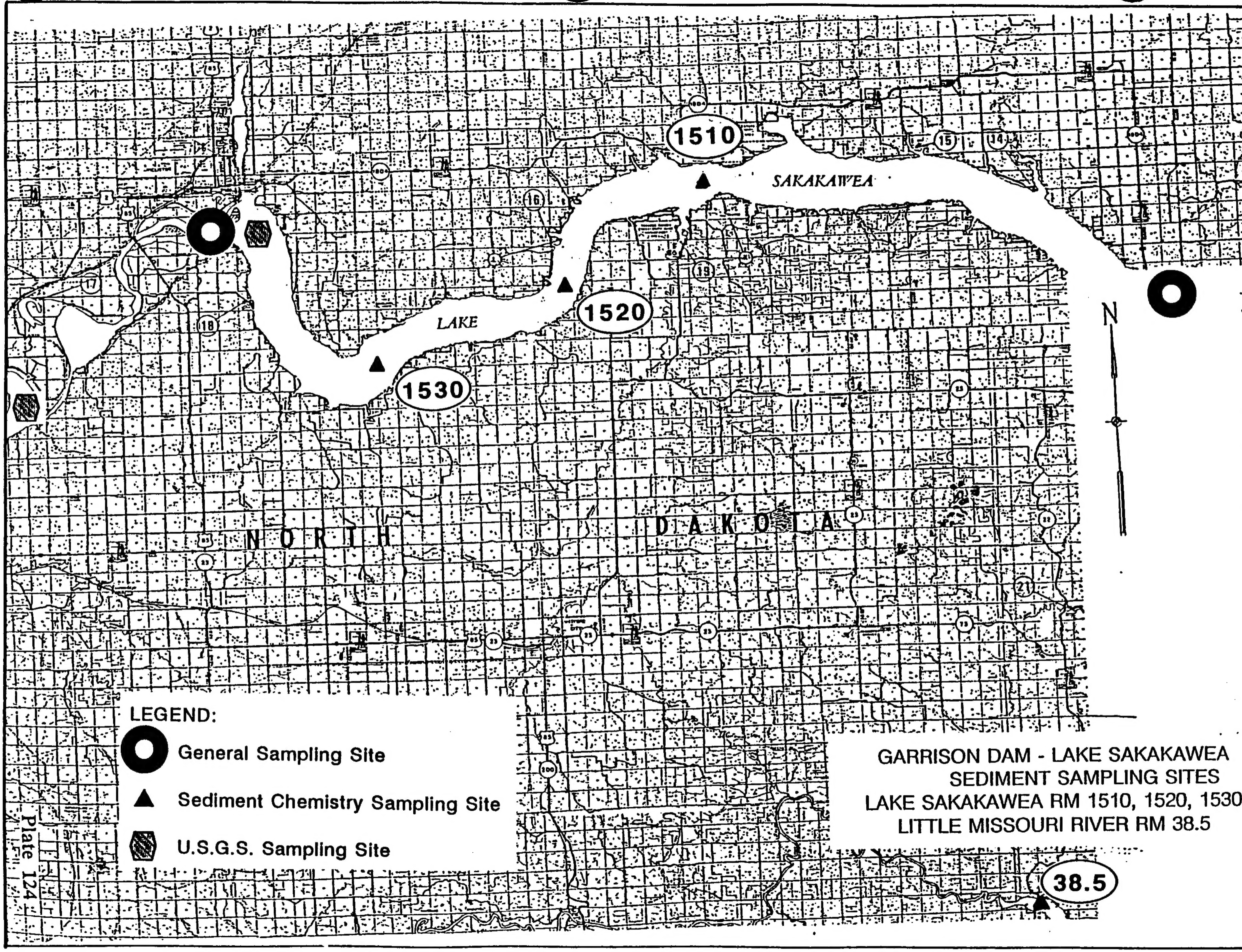


MONTANA
MALTA
GLASGOW
FORT PECK INDIAN RESERVATION
FORT BELKNAP INDIAN RESERVATION
PHILLIPS COUNTY
VALLEY COUNTY
FERGUS COUNTY
GARFIELD COUNTY
McCONE COUNTY
PETROLEUM COUNTY
FORT PECK
MISSOURI RIVER
FORT PECK LAKE
CHARLES M. RUSSELL NATIONAL WILDLIFE RANGE
U. L. BEND NATIONAL WILDLIFE REFUGE
C.M.R. N.W.R.
1805
1820
1840
1878
N
LEGEND:
General Sampling Site
Sediment Chemistry Sampling Site
U.S.G.S. Sampling Site
FORT PECK LAKE
SEDIMENT SAMPLING SITES
FORT PECK LAKE RM 1805, 1820, 1840, 1878



1480
0
7
15
LAKE
SAKAKAWEA
NORTH DAKOTA
LAKE AUDUBON
LEGEND:
General Sampling Site
Sediment Chemistry Sampling Site
U.S.G.S. Sampling Site
GARRISON DAM - LAKE SAKAKAWEA
SEDIMENT SAMPLING SITES
LITTLE MISSOURI RIVER RM 0, 7, 15

Plate 123



GARRISON DAM - LAKE SAKAKAWEA
SEDIMENT SAMPLING SITES
LAKE SAKAKAWEA RM 1510, 1520, 1530
LITTLE MISSOURI RIVER RM 38.5
LEGEND:
General Sampling Site
Sediment Chemistry Sampling Site
U.S.G.S. Sampling Site
LAKE
SAKAKAWEA
NORTH
DAKOTA
1510
1520
1530
38.5
N

Plate 124

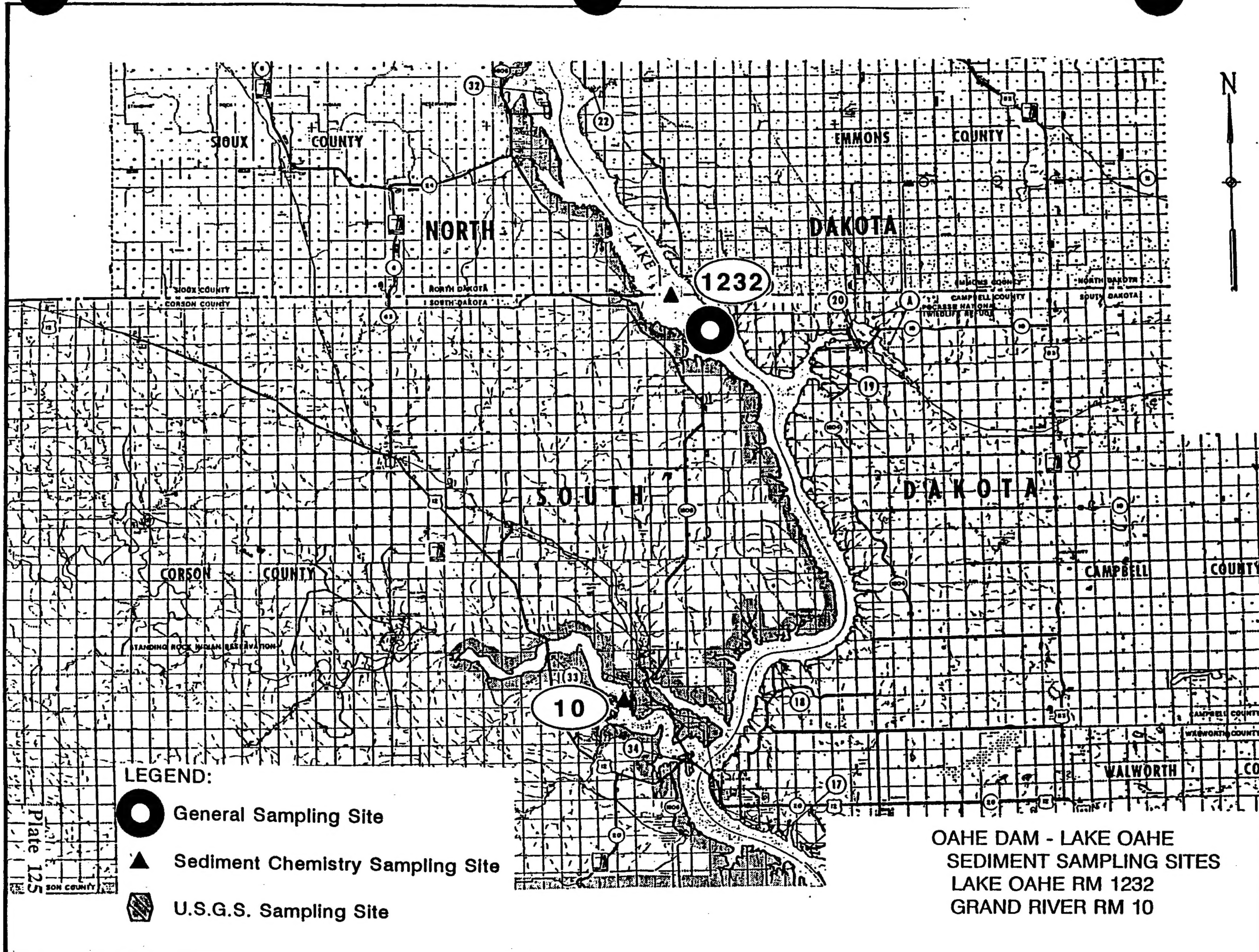
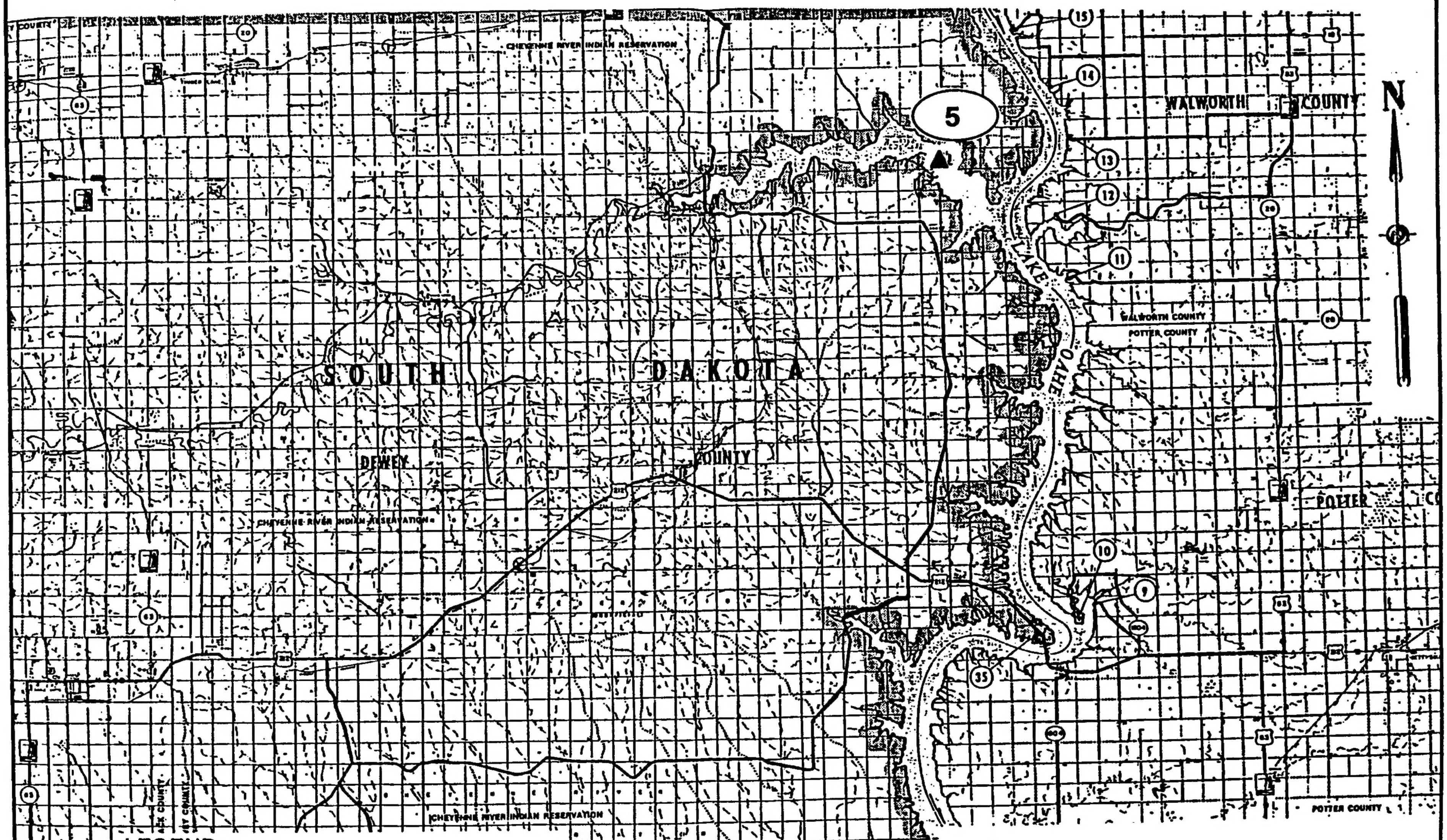

N
SIOUX COUNTY
EMMONS COUNTY
NORTH DAKOTA
LAKE
1232
10
SIOUX COUNTY
CORSON COUNTY
NORTH DAKOTA
SOUTH DAKOTA
SOUTH DAKOTA
CORSON COUNTY
STANDING ROCK INDIAN RESERVATION
CAMPBELL COUNTY
WALWORTH
LEGEND:
General Sampling Site
Sediment Chemistry Sampling Site
U.S.G.S. Sampling Site
OAHE DAM - LAKE OAHE
SEDIMENT SAMPLING SITES
LAKE OAHE RM 1232
GRAND RIVER RM 10

Plate 125



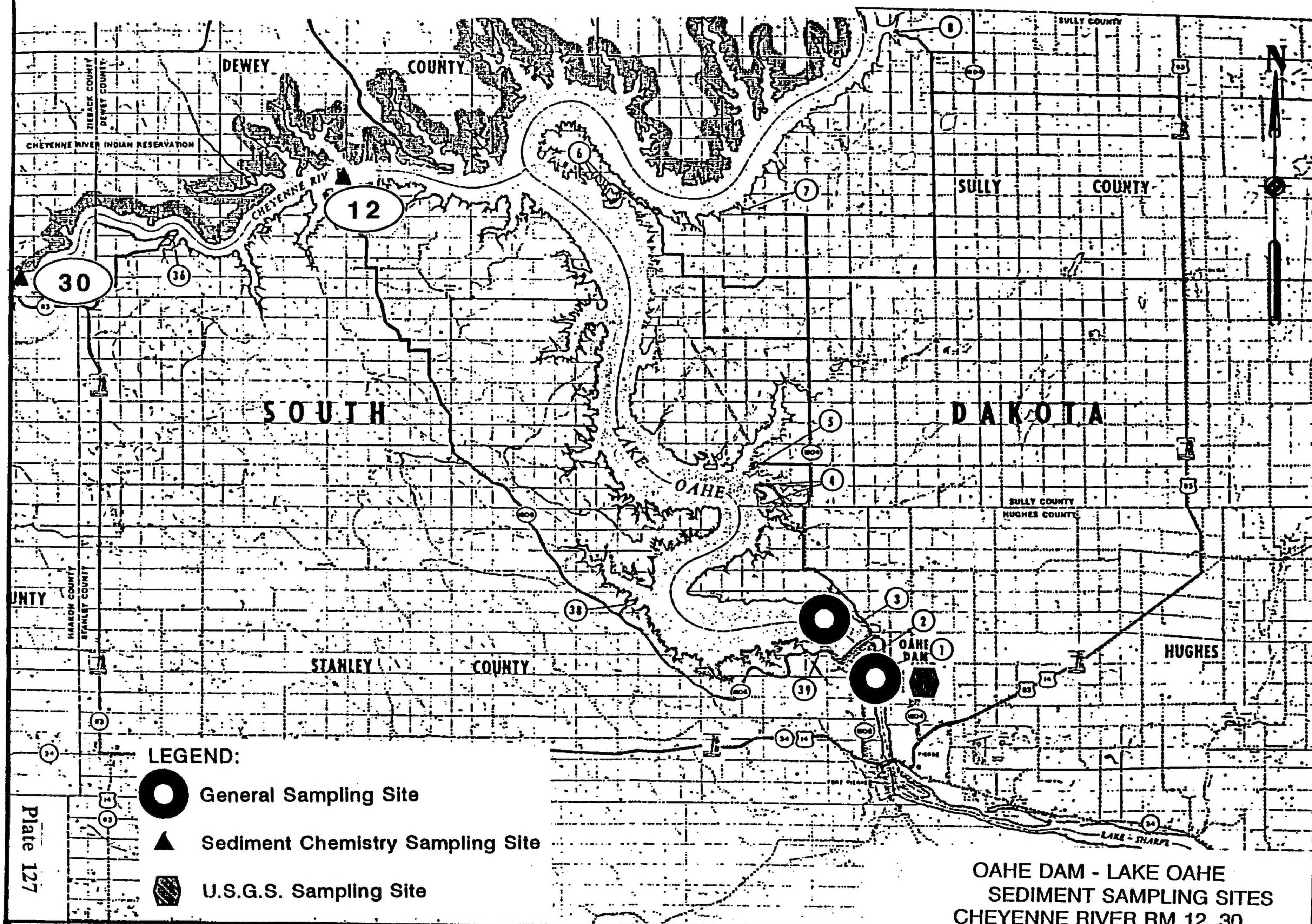
LEGEND:

General Sampling Site

Sediment Chemistry Sampling Site

U.S.G.S. Sampling Site

OAHE DAM - LAKE OAHE
SEDIMENT SAMPLING SITES
MOREAU RIVER RM 5


DEWEY
COUNTY
ZIEBACK COUNTY
DEWEY COUNTY
CHEYENNE RIVER INDIAN RESERVATION
CHEYENNE RIV
12
30
36
6
7
8
SULLY COUNTY
SULLY
COUNTY
SOUTH
DAKOTA
LAKE OAHE
5
4
SULLY COUNTY
HUGHES COUNTY
38
3
2
1
OAHE DAM
39
HUGHES
STANLEY
COUNTY
HAAKON COUNTY
STANLEY COUNTY
LAKE SHARPE
N
LEGEND:
General Sampling Site
Sediment Chemistry Sampling Site
U.S.G.S. Sampling Site
OAHE DAM - LAKE OAHE
SEDIMENT SAMPLING SITES
CHEYENNE RIVER RM 12, 30